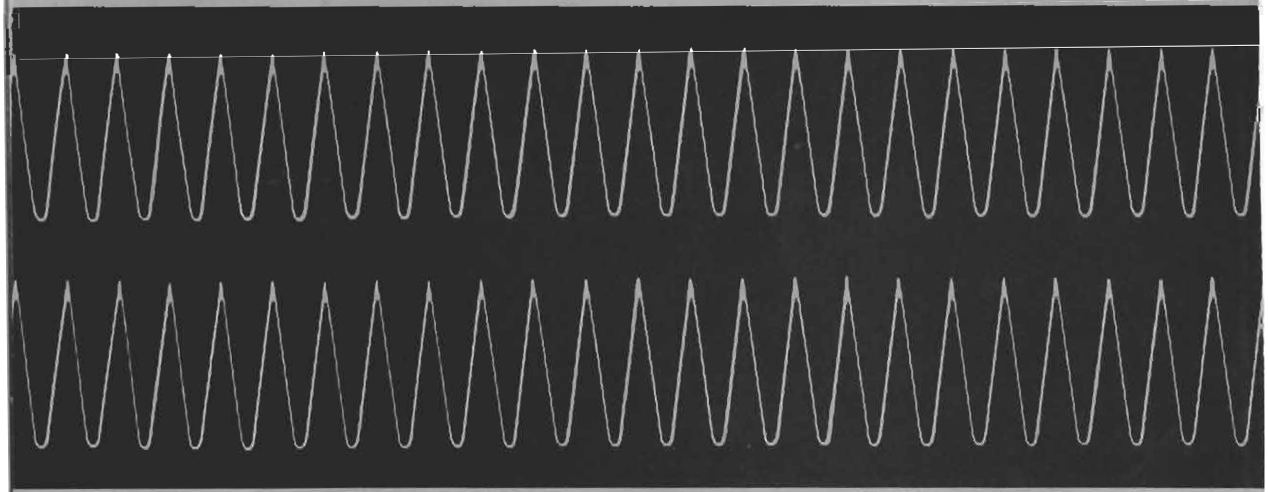
Noise as a Public Health Hazard

Proceedings of the Conference



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Proceedings of the Conference
Noise as a Public Health Hazard

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Proceedings of the Conference

Noise as a Public Health Hazard

Washington, D. C.—June 13-14, 1968

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Foreword

Noise—in the sense of "unwanted sound"—has been a problem since Eve first poked Adam in the remaining ribs and told him to stop snoring. As time went on and the population increased, we have become even noisier until today it seems that man-made sound of one sort or another bombards our ears almost continually. The problem of noise has become so great that it is regarded as a special type of air pollution and, as such, is judged by many as a problem whose control might well lie within Federal jurisdiction.

The Conference on Noise as a Public Health Hazard, held in Washington, D.C., on June 13 and 14, 1968, was organized in an effort to present the best evidence available bearing on the general question: To what extent is noise a public health hazard? An attempt was made to secure speakers who would present a broad picture of the noise problem: speakers who would not only summarize the relevant facts and theories dealing with noise and hearing loss, and discuss psychological reactions to intense noise and community complaints about sonic booms, but also explore opinions and prejudices that influence psychological reactions of individuals to those noises that could not conceivably affect their hearing.

Experts from this country and from Europe—where the problems of community noises are extreme due to high population density and where national noise control is accepted as a matter of course—were called on for position papers relevant to the problem of noise. It is hoped that the end product, this collection of the addresses, analyses, and discussion of the Conference, will give the reader a basic knowledge of the most recent scientific, political, social, and psychological issues involved in the effects and control of noise.

THE EDITORS

W. Dixon Ward
James E. Fricke

Acknowledgment

The idea for the Conference was developed through the work of William E. Castle, then Associate Secretary of the American Speech and Hearing Association, and George Urban, then of the Neurological and Sensory Disease Control Program, U.S. Public Health Service.

We are indebted to them and to fellow members of the Project Committee: Leo G. Doerfler, Ira J. Hirsh, Arnold M. Small, and Lennart L. Kopra, Chairman. Alexander Cohen of the National Center for Urban and Industrial Health, U.S. Public Health Service, served as co-project officer with George Urban.

A final special word of thanks is due the various persons cooperating in publishing this document: the authors of the papers who worked so diligently in preparing their manuscripts for publication; Frances S. Lichtenberg, Project Assistant, who took care of the necessary administrative and liaison details; and Frederick H. Goldbecker, former Publications Manager in the ASHA National Office, and Carolyn Wyte Bachand, Editorial Assistant, who coordinated the final editing and production of this publication.

THE EDITORS

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Opening Session

Welcome

Lennart Kopra*

University of Texas, Austin, Texas

On behalf of the American Speech and Hearing Association, it is my pleasure to welcome you to the National Conference on Noise as a Public Health Hazard. This conference is supported by the National Center for Chronic Disease Control, and the National Center for Urban and Industrial Health, Bureau for Disease Prevention and Environmental Control, U.S. Public Health Service.

The American Speech and Hearing Association's Project Planning Committee includes Leo Doerfler, University of Pittsburgh, Ira Hirsh, Washington University at St. Louis, Arnold Small, University of Iowa, and Dixon Ward, University of Minnesota. The project directors for this conference from the National Office of the American Speech and Hearing Association have been William Castle, who recently moved to the Rochester Technical Institute for the Deaf, and Castle's successor, James Fricke, who took over the more recent direction of this project. Alexander Cohen and George Urban have served as project officers for the Public Health Service.

Man's concern about noise and about its effect on him is not a recent development. During the Second World War and immediately following it, significant research, in which several of our participants today were actively engaged, was conducted on the effects of noise on human behavior, particularly auditory behavior.

In the late 1940s concern about the effects of noise on human behavior increased among scientists, physicians, architects, manufacturers, and civic authorities. Several conferences and meetings on the subject of noise were held during the early 1950s. The proceedings of one of these conferences on in-service training courses, titled "The Acoustical Spectrum, Sound Wanted and Unwanted," sponsored by the University of Michigan School of Public Health and the Institute of Industrial Health, represents an early textbook on noise: its causes, effects, measurement, costs, and control.

Other efforts to critically examine the various aspects of noise were the several symposia that were conducted beginning in 1950, which were co-sponsored by the Armour Research Foundation of the Illinois Institute of

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* Chairman of the Conference Project Committee.

Technology and the National Noise Abatement Council. The proceedings of the first National Noise Abatement Symposium were published in 1950.

During the past two or more decades extensive research has been carried out on noise and its various effects on man, his behavior and his environment, and scientific literature abounds with reports of this research. One might then ask, "Why is this conference today necessary?" Most of us who have asked this question have concluded that it is necessary to provide an opportunity for the various participants not only to learn of the increased complexity inherent in a study of the problem of noise and its control, but also to provide these persons an opportunity to interact, to interrelate, and, most important, to communicate with each other. New questions should come from such interaction and communication: new insights, new motivations, and a new understanding of the potential impact that noise in our environment may have in the future.

It is important to continually review and evaluate the intrusions man makes into the environment upon which life depends. A multiplicity of questions can be asked. For example: What synergistic effects might exist because of alterations in our environment from pesticides, chemical fertilizers, defoliants, automotive vehicles, and noise?

With his advances in science and in technology, man has become the major creator of pollution and is the only species potentially capable of destroying the only environment he has. But he is also capable of planning its preservation. This, then, is the reason for this conference, and I welcome you and wish you a profitable and stimulating experience.

Welcome

Richard Prindle

Bureau of Disease Prevention and Environmental Control, Washington, D. C.

On behalf of the Public Health Service, I welcome you to the first National Conference on Noise as a Public Health Hazard. I wish to express our appreciation to the American Speech and Hearing Association, who, as co-sponsors, insured that the conference would be a true reflection of all those disciplines and organizations having particular interest in the noise problem.

Professional public health is today concerned with two closely related objectives: preventing premature death and disability, and enhancing the quality of human life. I submit that this latter objective is becoming more and more important daily as we progress into this polluted world.

There are cogent reasons for believing that noise prevention and abatement are related to the successful attainment of both these goals, but, like the weather, everyone talks about noise; nobody does anything about it. We hope this conference will be a historical landmark: the point in time when something began to be done about noise.

As a press release announcing this meeting stated, noise goes on trial at this Conference. Our purpose is to provide a forum for serious discussion of all aspects of noise as a health hazard, and to identify the research needed to delineate the scope of this problem. All facets of noise and its effect on man in his home, at his work, and in the community, will be examined by experts from this country and Europe. We anticipate that from your discussions will emerge recommendations to which not only the Public Health Service, but also other concerned organizations, will be able to respond. Your recommendations will suggest, we hope, practical opportunities and methods for doing something to control noise in man's environment: control methods that will better safeguard health and also improve the quality of living in the industrialized, urbanized environment of today and in the future.

We want expecially to acknowledge the professional interest and the sense of public spirit which caused each of you to take time out from your busy schedule to come here. Again, welcome, and we're honored by your presence. Good luck to your endeavors.

It is now my pleasure to introduce a man who for the last several years has helped guide an extensive restructuring of health programs, not only in the Department of Health, Education, and Welfare, but in health planning throughout this country. These organizational changes at the Federal level became necessary because of the many new responsibilities placed on the Department of Health, Education, and Welfare by Congress in recent years. Especially noteworthy are those laws relating to Medicare, Medicaid, air pollution control, the racial medical programs, and Partnership in Health. As you know, this last legislation placed responsibility for comprehensive health planning on the state and local levels, and should, in time, generate decisive improvements in public health services throughout the country.

It pleases me very much to introduce one of the principal architects of all this, William H. Stewart, Surgeon General of the Public Health Service.

Keynote Address

William H. Stewart

Public Health Service, U. S. Department of Health, Education, and Welfare
Washington, D. C.

I would first like to define a few terms. I won't defend the definitions; I'll just say that's the way we operate. One of the beauties of working in the public health field is that we define public health as the health of the public, and we also define health as well-being, very similar to the World Health Organization's definition. The beauty of this is it allows one to work in almost anything. It has some drawbacks in the sense that a public health person can never be an expert. His real job is to mobilize expertise—to define those things that are impinging upon the well-being, and to mobilize that expertise to do something about these things so defined.

When the chips are down, when definitions are made, when judgments must be made, he always must lean on the side of the public. So these are my definitions of public health and they shade what I have to say.

Twenty years ago this fall, in the town of Donora, Pennsylvania, a combination of unusual weather conditions and fumes from local factories produced an air pollution episode during which 20 people died and hundreds more were made acutely ill. The same sort of thing had been happening for a number of years, on a larger but less intensive scale, in England, Belgium, and elsewhere. But Donora was America's first dramatic confrontation with air pollution as a major health menace.

Ten years later, in 1958, Leroy Burney, then Surgeon General, called the First National Conference on Air Pollution, here in Washington. In his opening remarks, Burney described the state of the art in air pollution—limited areas of knowledge and great areas of unexplored territory. Then he made this observation:

> Referring to the circumstantial evidence relating cancer to atmospheric pollution, I remarked that the case has not yet been proved. This legal metaphor is frequently used. I submit to you that it is misleading.
>
> In law, the suspect is innocent until his guilt has been proved beyond reasonable doubt. In the protection of human health, such absolute proof often comes late. To wait for it is to invite disaster, or at least to suffer unnecessarily through long periods of time.

In welcoming you to this First National Conference on Noise as a Public

Health Hazard, I am forcefully reminded of a number of parallels with this earlier situation.

This marks the first time that noise, as a health factor, has been the subject of a national meeting convened by a governmental agency in partnership with a national association. Our knowledge of noise now—the state of the art—is characterized by excellent data produced by very good research in certain limited areas, surrounded by great chunks of territory waiting to be investigated.

Moreover, attitudes concerning noise as a health hazard now are analogous with attitudes toward air pollution in 1958. At that first Conference there were a number of voices saying, in effect, "Air pollution problem? What air pollution problem? I don't smell anything." Today there are apologists for some of the noisier phenomena in our society saying, "I don't hear anything."

Of course, we haven't had our Donora episode in the noise field. Perhaps we never will. More likely, our Donora incidents are occurring day by day, in communities across the Nation—not in terms of 20 deaths specifically attributable to a surfeit of noise, but in terms of many more than 20 ulcers, cardiovascular problems, psychoses, and neuroses for which the noise of 20th century living are a major contributory cause.

Must we wait until we prove every link in the chain of causation? I stand firmly with Burney's statement of 10 years ago. In protecting health, absolute proof comes late. To wait for it is to invite disaster or to prolong suffering unnecessarily.

I submit that those things within man's power to control which impact upon the individual in a negative way, which infringe upon his sense of integrity, and interrupt his pursuit of fulfillment, are hazards to the public health. A case of polio, an episode of smog, and a sonic boom all carry such an impact.

Having said this I am not suggesting that all such hazards must, or can, or even should be eliminated from man's environment. We can not wrap ourselves in an impenetrable blanket or live out our lives in the hazardless environment of a padded cell. Indeed a good case can be made that a degree of hazard is not only desirable but essential to individual fulfillment. The human organism, like the human spirit, responds to challenge.

The questions are, what kind of challenge? Challenge to what purpose? At what point does needless challenge become insult, in both the biological and the general sense of the word? Several decades ago T. S. Eliot wrote: "This is the way the world ends, not with a bang but a whimper." Must we look ahead to a world that does not end but goes on with ever-increasing banging and non-stop whimpering?

I think not. I think we can choose our challenges, at least to the degree that these challenges are produced by our own cleverness. We who have been smart enough to dream and realize the genuine wonders of 20th century civilization are smart enough to select and temper its insulting by-products.

Consider, for example, the paradox of the modern city. Querido, a professor in the Netherlands, in a recent issue of *World Health,* notes that the city was brought into being by the social urge of man, for mutual safety and improved intercommunication. It succeeded up to a point, but in the process generated new dangers for human well-being and new impediments to meaningful communication.

He said this:

> It is only too easy to illustrate this state of affairs. Telephoning becomes maddening—literally so. There are no adjectives to describe the anti-functioning of elevators and subway services. And what about surface traffic, which makes the more advanced participants revert to carrier-pigeons in order to inform the family that . . . the head of the family is caught in a traffic jam which is indeterminable in space and time? In the modern city our senses are assaulted just as much as they would have been some hundreds of years ago. . . . There is noise and stench, perhaps the more unbearable as it is more mechanical, more impersonal, more relentless because there is less opportunity for escape.

What Querido was describing is the contemporary condition of urban man. Is it good? If not, is it necessary? Who's in charge here?

As with virtually every public health problem, we have entered the contest against needless noise rather late. The hazard has a long head start. Yet it is encouraging that we are starting before, rather than after, the impact of obvious crisis on which most of our constructive actions unfortunately wait. Still more encouraging is the fact that we begin our confrontation with noise as a generalized public health hazard on a strong base of knowledge concerning occupational exposures.

Specifically, we know that excessive noise exposure causes hearing loss. We know that hearing acuity of selected groups of exposed workers is significantly poorer than that of nonexposed comparable groups. Histological studies have confirmed cellular destruction in the hearing organ directly related to the specific frequency and intensity characteristics of noise. We know also, on the basis of surveys, that perhaps half the machines in industrial use produce noise levels intense enough to pose a hazard to the hearing of exposed workers. As much as 10 years ago it was estimated that as many as 6 million people worked in noise conditions that might be damaging, and other estimates run as high as 16.5 million.

Aside from hearing loss, it has been demonstrated that noise can cause physiological changes. These include cardiovascular, glandular, and respiratory effects reflective of a generalized stress reaction. These changes are typically produced by intense sounds of sudden onset—the sonic boom is the most frequently cited example—but can also occur under sustained high level, or even moderately high, noise conditions.

Still to be explored, of course, are a broad range of problems underlying and surrounding these observations. We need to know more about how noise damages hearing. We need to know more about the effects of noise on performance and work efficiency in the job setting. And, of course, we need to extend our knowledge outward into the community where people live—to the worlds of jackhammers and power mowers and booming hi-fi sets and screeching airplanes that we call home. We need to look ahead just a few short years to the awesome potential of the Supersonic Transport Age. We need to find out, before it happens, whether or not we may find ourselves existing in a coast-to-coast drop-forge foundry, to borrow the phrase of William W. Proxmire, the Senator from Wisconsin.

Meanwhile, proceeding from the knowledge we have, a number of constructive actions have already been taken and more are in prospect. Just this week the House of Representatives passed—by the significant margin of 312 to 0—a measure directing the Federal Aviation Administrator to set and enforce standards for aircraft noise abatement. This legislation is now before the Senate. The Occupational Safety and Health Act, also before the Congress this year, contains, among its many beneficial provisions, further control of noise on the industrial site. A number of the states already have effective noise control legislation, particularly in the occupational field. For some time California has had a law providing for control of motor vehicle noise, and New Jersey is now considering similar legislation. Cities have even gone so far as to abridge what some consider the divine right to blast their fellow bus riders with transistor radios.

Meanwhile, underlying and helping to motivate these actions, there is a clearly detectable groundswell of public anger over the public indignity of the sound barrage. Letters are being written, to editors and congressmen. Committees are being formed—many of them, like the Citizens League Against Sonic Boom, numbering among their membership distinguished scientists, writers, and conservationists. As in similar movements, these people come from a diversity of backgrounds. They are brought together by a common concern for the common condition of man.

Almost in parenthesis I might add the encouraging note that noise abatement is becoming increasingly a subject for humor in the public media. Within the last couple of months at least one major television comedy show has done a full-length skit on noise in the vicinity of an airport. The *New Yorker* and several other magazines have run cartoons. If anyone's sensitivities are wounded when his serious cause is treated frivolously, he should take comfort in the fact that Los Angeles smog was a standing gag for comedians long before air pollution control became a national crusade. I'm not suggesting a cause-and-effect relationship, but certainly the humor didn't hurt the cause.

What is the cause? Stated in its simplest terms: The cause is the quality of human living. In this society we have fixed our dream on individual self-fulfillment. When the individual human being is jolted, distracted, or disturbed—in work or leisure—by noise that need not assail him, his very fundamental right to the pursuit of fulfillment is impaired.

And if the quality of living is the cause, the harnessing of technology to human ends is the issue we confront here. A few weeks ago an article appeared in the *Saturday Review* by Wilbur Ferry, who wrote this:

> I shall argue that technology is merely a collection of means, some of them praiseworthy, others contemptible and inhumane. There is a growing

> list of things we can do that we must not do. My view is that toxic and tonic potentialities are mingled in technology and that our most challenging task is to sort them out.

My own profession of medicine is having serious problems sorting out the tonic from the toxic potentialities of its new technology. Every day physicians face the temptation to do something just because it can be done. The temptation is made harder to resist by the fact that technology presents its case in clean, sharp, objective terms which need to be measured against the old, fuzzy, subjective yardstick of human purpose.

Yet that is the measurement that counts. For every new possibility that technology offers, the questions must be put: for the benefit of whom, and at what collateral hazard to the beneficiary and to others? Public Health, a discipline rooted in concern for the quality of living, has three functions here: to help frame the questions, to help define and quantify benefit and hazard, and to represent the health of the people in the decision-making process.

In this framework noise is indeed a public health hazard, a matter for public health concern. And in this framework few things that we shall do this year are more timely, more appropriate, more necessary than this Conference.

Introductory Address

Walter A. Rosenblith

Massachusetts Institute of Technology, Cambridge, Massachusetts

I should like to examine the conceptual framework in which we view observations and data. Having critically inspected the conceptual machinery with the aid of which we try to relate the effects of noise on man to the characteristics of both noise and man, I shall conclude with a few remarks on the relevant institutional setting in which we make our trade-offs and compromises.

I shall, in the main, try to raise questions about the extent to which changes in our views of sensory processes and brain function within the last two decades have changed the intellectual climate in which we examine the effects of noise on man.

Like other pollution problems, noise is a negative fringe benefit of the man-made environment of our industrial and high-density, urban society. To the extent, then, to which this environment is becoming increasingly man-made, noise is not likely to go away, but only to become more pervasive. Thus the only realistic strategy to lessen the impact of noise upon man's activities and well-being consists in committing our society to a more rational application of its technological potential. We clearly cannot reduce noise by dreaming about a Thoreauvian utopia. Instead, if we are indeed concerned with the quality of our environment, we must be willing to pay something akin to a technological insurance premium whose amount is proportionate to the improvident use of technology which has made noise the problem it is.

Noise often arises because man flexes his technological muscle in pursuit of a definable and technically attainable purpose. "Let's get there faster," or, "Let's produce this item more cheaply," are slogans which symbolize the impetus for this type of achievement. These special purposes or economic advantages are not necessarily selfish, either for an individual or for a group. But they may interfere or even clash with other purposes of the very same or other groups.

Maybe the purest illustration of this conflict relates to man's ambition to "hear the music the way it is, baby." Contemporary technology permits hi-fi sets to emit an acoustic spray that covers other people's territory. The music-maker (or noisemaker) always has a special relation to the sounds he produces or controls; he does not hear them the way others do.

Ever since scientists from different fields have studied problems created by noise, most researchers have attempted to import paradigms from physics, and to some extent from psychophysics: We have tried to analyze the situation by correlating input (measured by physical apparatus) and output (which stands here for the physical, physiological, psychological, social, economic and even political consequences). In this way we have talked about cause and effect and we have talked about stimulus and response. And somehow we have hoped that, whatever it was that lay in between, i.e., between the stimulus and the response—even if it didn't have the shape of a black box—was nevertheless, for practical purposes, going to behave like a black box, if we just knew the right way of doing the experiment or of organizing our observations. At the most we were willing to admit that the bugaboo of variability might make it a more or less probabilistic black box.

Now, then, I think the time has come to ask ourselves: To what extent is this really true? But before I do, let me briefly examine the broad classes of noise effects in their traditional division, and the distinctions between the ways and areas in which this approach is and is not successful.

I think it is fair to say that there is still a great deal that we do not know about individual hearing and hearing loss. We are still far from understanding the intricate mechanical and biochemical mechanisms that have something to do with the way in which individuals (in contrast to populations) exhibit hearing loss as a consequence of a reasonably well-defined noise exposure. But, by and large, in this area we are really not that far from being able to talk of statistical relationships that relate effect to exposure.

We must be very careful when we talk about populations—for indeed, they should be fairly well-defined populations. We must not overlook the problem of the aged. We must not overlook previous history of exposure, and, in general, we have not a very good way of describing these noise exposures yet. But, still, we have come a long way from the beginning when the secret formula seemed to be, "What's the noise level, Bud," and that was all that was necessary to tell.

So here we have the beginning of an understanding, without, though, a deep understanding of the mechanisms, and without, perhaps, a sufficient understanding of the problems from the viewpoint of individual variability. But, we can at least in principle think of a hyperspace that will describe the relations of hearing loss to noise exposure without too many singular points.

Now, to problems of speech communication. We have learned in the last 25 years—when concern with noise was institutionalized in a variety of places—that intelligibility, while highly dependent upon signal-to-noise ratio, is not independent of grammar. In other words, the structure of the message is extraordinarily important to what is going to happen at a given signal-to-noise ratio. Today we are able to combine our measurements of Speech Interference Level (so convenient for the acoustical engineer) with our assessment of the structure of a message into predictions of speech intelligibility. These predictions thus involve what happens at the level of man's hair cells with the expectations that inhabit man's brain.

So we have learned we can understand the problems of speech communication in the presence of noise, provided we really want to understand what the structure of the noise is, what the expectation of the subject is, and what the structure of the message is.

The next general class is a very broad class. It starts out with psychomotor performance and simple reaction-time experiments, and it ends up with very cognitive tasks indeed. And it is in this area of complex behavioral manifestations of man that the great trouble has arisen and the great trouble is man's brain. Man's brain, if you want to go back to the old black box experiment, is just not reasonably depicted by a black box with single inputs and single outputs and a *tabula rasa* history.

In general, when people want to do something in physics of a classical nature, they talk of initial conditions: e.g., what is the initial condition of the object when a certain force is being exerted upon it? Well, how are we going to describe the initial conditions of the brain? The original conditions of a man's brain, or a population's brain? Well, my view is that in order to dramatize we have really got to think of the box, i.e., the brain, as at least a pink box, a pink box with lots of outputs, with internally restructurable and reorganizable subsystems, a box that is not that easily described for a very simple reason: it has ten billion neurons. But, despite this fact, the brain isn't just a neuron gas, it isn't just a neuron fluid or a neuron solid; it is a very complexly interacting set of structures. The brain has approximately 10 to 100 times as many satellite cells as neurons, whose significance are just now being seriously investigated. So we are not just talking 10^{10}, but 10^{10} compared with 10^{11} or 10^{12}. The cerebellum, which is supposed to be the smallest part of the brain, really has 10^{11} neurons, so 10^{10} must be wrong. Also, your cerebellum, which is the most regularly structured part of the brain, has neurons with other neurons synapsed upon them—and not in trivial amounts. There are neurons in the cerebellum that, essentially, do a Gallup poll on the 200,000 synapses that end upon them. Thus describing how a neuron of the brain operates is complex; and determining which is an initial condition in an experiment is not easy.

Of course, some synapses are more important for certain neurons: they listen more carefully to some synapses than to others. And so, now, through electron microscopy, through what might be called microanatomy and microphysiology, and as I like to say, micrologic—because that's in some sense what the computer has helped us do—we have gained an insight into the structure and behavior of the brain that no longer permits us to have oversimplified views of it.

Basically what we have learned about man's brain is that there is a tremendous amount of specificity in parts of the brain, and there is an enormous amount of flexibility in others. The specificity is perhaps best illustrated by the findings of Hubel and Wiesel who found that many neurons in the visual cortex "like" particular kinds of visual display. The flexibility of the brain is perhaps best illustrated by the neuronal studies of Buser in France, who found neurons in the association cortex that seem to be interested in visual events for half an hour and then they seem to switch—for a reason that he has not been able to discover—to auditory events, and then to the skin, and so on.

We have also learned in the past 25 years that there are specific brain lesions that interfere with specific performance, but the whole problem of specificity and nonspecificity, lesions, sizes of lesions, and kinds of lesions depend, in a way, upon the task one gives the brain. What we need is a task hierarchy, a task taxonomy, for the more difficult the task the more sensitive the brain is to damage.

Today we know there are not just anatomical lesions; there are chemical lesions. How are we to put stress lesions, such as noise might produce, into perspective?

If we look at studies coming mainly, from England—Broadbent's Laboratory and others—in which man is seen as a single-channel processing device with the limitations that exist in such a device, then to understand the way man performs in various tasks we need a theory of attention. What does attention mean? How is attention related to stress? How do you have a theory of attention and the negative attention effects of various kinds of stresses? How does attention handicap a human being in relation to unexpected events? How is reaction time dependent on attention? How is time and allocation of time, information processing in the brain, related to these factors?

Next we have to ask ourselves: How has our increased knowledge of the older brain structures, especially the brain stem reticular formation, and our knowledge of the autonomic system, kept up with the experiments that we would like to do on arousal and startle, on sleep and even the very stages of sleep that have been discovered in the two decades that we have been referring to? Today the question of what kind of stress does what to what stage of sleep is a problem to investigate. The question of how the autonomic system reacts—the physiology of unexpectedness, of startle—needs to be better understood before we can have a reasonable, conceptual model of what a set of repeated startles means in the life of a population.

You know, we have developed a transportation system in this country that is fine for those people who are healthy and can run, or drive a car, or carry heavy luggage, but just think of those who cannot. Are we going to develop an acoustic environment that is good for all who have a certain level of mental health? This is a question that we have to ask ourselves; but when we ask it we run into a problem: if we only knew how to characterize mental health, everything would be fine.

During the last two decades phenomena of sensory deprivation have been much studied. These studies support a view that should not really surprise us, namely that organisms do not develop, live, and function well in a sensorily impoverished environment. We are still far from being able to define a normal metabolism with respect to sensory information processing, but we know already that optimal development does not occur in a silence generalized to all sense compartments. We should keep this in mind before we legislate too eagerly for what we call "desirable silence."

So far I have not touched upon community effects. There is a constraint that exists in communities where many events other than acoustic events characterize the total situation. Should I start talking about the trade-offs, of which, perhaps, the most trivial example is the distance from an airport and the noise that people are willing to put up with? With community effects, we need to consider institutional problems, economic problems, and, perhaps, we need to ask ourselves about the political climate in the country. Are people in general going to be fed up and impatient, or are they going to live in an environment in which being fed up and impatient provides an interesting topic for conversation—like the weather?

When we talk about public health, there is a dimension that has never been sufficiently looked at, and that is longitudinal studies. What happens to people after living a certain way for 40, 50, or 60 years? Every once in a while we read that we still don't know what the long-range effect of "the pill" is. Well, we do not know what the long-range effect of noise is either.

We can't reach conclusions yet, but we can assay what some of these long-range effects might be, if we set up systematic data collecting agencies. This is not easily done by universities so it is important to realize that we need other agencies to look out for pervasive and long-range effects. The Public Health Service has a unique role to play in this respect, but it should clearly play it in the kind of partnership that this Conference exemplifies.

Living in an environment in which there are so many options and opportunities, we must ask ourselves: How are we going to assess progress? What are the social indicators of progress? What do we mean by old and maybe not very meaningful phrases such as "the greatest good for the greatest number"?

It is not going to be easy to do the experiments, or the observations, or collect the data. The more involved we become with the brain—and in some sense I feel the involvement of noise with the brain and the involvement of air pollution with the brain are different kinds of problems—the more we must be willing to live with ambiguity and uncertainty. I do not think it will help to do research, instruct, carry out industrial activities, or even legislate, without being aware that when we talk about the effects of noise on human behavior we are talking about the most unknown and the most complex piece of matter there is in the universe: the human brain. Yet this does not mean that we should step away from it; it is simply that this knowledge of uncertainty is something we must be aware of; otherwise we are going to look for simple solutions, or even one solution.

I have not given you a social prescription, yet, two paragraphs from a speech that Robert F. Kennedy, Senator from New York, made in Los Angeles on April 19 are singularly relevant here.

> I have come here not simply to talk about dilemmas, but to examine our opportunities: the almost unlimited possibilities for liberating the body and mind of American citizens with the tool we now have before us. I come here to examine what we have and have done with our vast capacities. I come here to propose a new fusion between the genius of our private technology

> and the resources of public authority, to build an America where the citizen is not enslaved by technological achievement, but freed by it, where this resource is put to work not simply in improving the quality of our goods, but the quality of our lives.

Further on, he said this:

> These contrasts are not just California's. They are written across America. The benefits we reap from technology tell us how much can be done. The darker consequences tell us how much there is to do. America, I think, is coming to understand that indifference is a high price to pay for affluence. We are no longer willing to rest content with power boats if these boats make our water unfit for sustenance or recreation. We will not be satisfied merely with fine houses if they are built from the last of America's redwoods. We no longer want more and more modern highways if they pave over irreplaceable scenic wonders and if inner-city neighborhoods are destroyed in the process. What all of us sense is that the wonder we have at our hand is the modern progeny of fire: a profitable, valuable aid if we are wise enough to harness it; a dangerous, destructive enemy if we are foolish enough to let it master us. We now understand that the use of modern capability, like the lighting of a fire, guarantees no success, and may wreak enormous harm if it is put to use in the service of dubious ends.

The next paragraph is perhaps the most relevant to the way each of us can do our part when it comes to noise:

> . . . for we are coming to understand that the errors of the past were not just failures to put the private interest ahead of public good. Too often we have been without a clear conception of what the public interest was, and therefore all of us, almost for lack of anything better to do, have built our own piece of a nation in our own way. And the pieces do not match.

Primer on Methods and Scales of Noise Measurement

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Since this Conference is of interest to persons in fields unrelated to physical and psychological acoustics, the Conference Committee felt it desirable to review briefly at the outset the methods used at present to measure the physical and psychological attributes of sound. The Committee was aware, too, that the terminology in each paper following presupposes a certain level of understanding. Therefore, I shall attempt here to provide this level of understanding as well as to present information which will minimize the need for each individual speaker to digress from his main theme to describe how and why he utilized particular techniques to obtain his data, and why the data are presented in certain ways.

Attributes of Sound Waves

It is appropriate to begin by commenting briefly on the nature of sound waves since many of the measurements under consideration are keyed to the fundamental properties of sound and because the reasons and necessities for using special procedures are intimately involved with the properties of the sound wave.

Sound, as we know it, is propagated in the form of a compressional wave. The fact that it is a compressional wave demands that the wave must move in a physical medium of some sort which can be compressed and rarefied. Sound waves are almost always referred to as compressional rather than rarefactional waves. We tend to overlook that, for airborne sounds, symmetry of waveforms ceases to exist when the amplitude of rarefaction reaches a peak value of one atmosphere, because there is nothing left to "rarefy." In a world where energy is sometimes measured in megatons of explosives, we must constantly remind ourselves that even for extremely loud sounds the total amount of energy in a sound wave is usually quite small. It follows then that the forces which sound waves can exert should be categorized as moderate to small. Only when one talks of extremely loud sounds will this classification be subject to modification.

Most of the sounds to be discussed here will be those propagated through our atmosphere. As the atmosphere is compressed and rarefied by these sound waves, a very small fluctuation in the barometric pressure, attributable to the passage of the sound wave, occurs. Although there are other measurable attributes of the sound wave, it is almost a certainty that, at this Conference, all of the data reported relating to the amplitude of the sound wave will have been measured by pressure-operated microphones sensitive to fluctuations in barometric pressure.

✓ Two major classifications of sound wave types are used in acoustics: plane waves and spherical waves. These names are derived from the geometric description of the wave front, the area occupied by the forward part of the pressure disturbance. A plane wave results, in general, if the source is large, if the measuring point is at a long distance from the source, and if there are no reflecting surfaces of any kind between the source and the measuring point. Under these conditions the forward edge of the wave will lie on the surface of a flat sheet or plane which is perpendicular to the direction of propagation of the wave. Measurement of a plane wave's pressure is simplified because the microphone location is essentially unimportant as long as it remains in the plane or one parallel to it.

The spherical wave is classically described as the type of radiation coming from a small pulsating sphere where the point of measurement is reasonably close to the sphere and there are no reflecting surfaces in the vicinity of the source or the point of measurement. If one were to obtain an instantaneous snapshot of the pressure distribution of the forward part of such a wave, it would be evident that the maximum pressure, for example, would lie on the surface of a sphere with the center of the sphere located at the pulsating source. It should be pointed out that as one gets farther and farther from a spherical source, a reasonably small section of the forward wave front would occupy an area approaching a flat plane.

One important feature of a plane wave is that the pressure amplitude does not change with distance unless there is some form of absorption or dissipation in the medium as the wave travels through the medium. In the case of the spherical wave, the pressure amplitude decreases as the wave travels farther from its source, and this decrease is commonly referred to as the "inverse square law" change in amplitude. Since any real medium departs from an "ideal" medium, there is always some amount of dissipation of a sound wave as it advances through a medium. This dissipation represents a loss of energy, and the amplitude of the sound wave is affected by this loss of energy. Thus the amplitudes of plane waves do decrease with increasing distance and spherical waves lose energy at a greater rate than the inverse square law (6 dB/double distance) would predict.

Fields of Measurement

It is important in measuring sound waves to recognize the various characteristics of plane and spherical waves. One must also recognize that interpretation of data depends not only upon the measurement of a sound wave's pressure amplitude but also upon the location of the measuring microphone. Points of measurement are commonly referred to as "far field" and "near field." These words are so descriptive that they need little interpretation except to explain one fundamental question: When is the measuring point in the far field and when is it in the near field? For simplicity let us assume that measurements are being made in an environment which is far removed from any reflecting surfaces. Such environments can be realized in a laboratory by providing highly efficient absorbing materials for wall surfaces, as in an anechoic chamber. In such an environment, a measuring point is considered to be in the far field if, by increasing somewhat the distance of the measuring point from a small source, the pressure measurement change follows the inverse square law, i.e., as the distance from the source is doubled the measured sound pressure level decreases by 6 dB. An engineering rule of thumb commonly used to specify a measuring position as being in the far field is that the measuring point should be at least several wavelengths, or several times the circumference of the source, whichever is larger, from the source.

The near field of a source is defined as that region where changes in pressure amplitudes do not obey the inverse square law. Normally such positions are within a few wavelengths of the source. A transitional region clearly exists between the near field and the far field as one increases the distance from the source to the measuring point. Unfortunately, the mathematical description of the wave in this transitional region is far from simple. In practice one tries to avoid making measurements in the transitional region, but in real life it is sometimes impossible to avoid making measurements within this ill-defined space.

Relationship of Media to Sound Propagation

At this point I wish to consider how the media affect the movement, or propagation, of sound waves, and to point out certain features of the waves that are altered when sound travels from one medium to another. Since a sound wave represents a pressure disturbance in a medium, and since this pressure disturbance moves through the medium, there must clearly be a certain speed of propagation of this pressure disturbance. The speed of sound within any medium depends upon the compressibility of the medium and upon the density of the medium. If the medium is solid, such as a metal bar, and the sound wave is being transmitted along the bar in the direction of its length, then the compressibility is defined by a term called "Young's modulus." If the medium is a fluid or a gas, the compressibility is given in terms of the bulk modulus of the fluid or gas. For most of the sounds to be discussed, the elasticity, or bulk modulus, of the medium is solely a property of the medium and does not depend upon the rate of compression or upon the amplitude of compression of the medium. Thus the speed of sound does not depend upon the frequency or amplitude of the sound wave but only upon the medium. The uninitiated cannot appreciate the simplification which results as a consequence of this statement, but if this were not true, then sounds would change in quality as a function of distance from the source, and waveform or shape would change as the wave moves, etc.

As a sound wave travels from one medium to another, certain changes in the wave do, however, take place. It is important to understand these changes and to recognize how the characteristics of the media affect the changes. Since the frequency of a sound wave depends upon the source which created it; since the speed of propagation of a sound wave depends only upon the medium; and since the wavelength of a sound wave equals the speed of propagation divided by the frequency (a relationship which I must draw from thin air for lack of time), it follows that when the sound moves from one medium to another there is a change in wavelength. To illustrate the point, consider a sound wave traveling from air into water. Since the speed of sound is approximately four times as great in water as in air, the wavelength of a given frequency of sound in water will be four times as great as the wavelength of the same frequency in air.

Another important change that takes place as sound travels from one medium to another is a change in the pressure amplitude of the sound wave. As a sound wave strikes the boundary between two media, a reflected wave comes back with respect to the original wave and travels in the same medium as the original wave. In general, there will also be a wave transmitted into the second medium, and the pressure amplitude of this wave must obviously be less than the pressure amplitude of the original wave. Similarly, the pressure amplitude of the reflected wave must also be less than the pressure amplitude of the original wave, otherwise the law of conservation of energy is violated. The question of whether the pressure amplitude of the reflected wave is greater or less than the pressure amplitude of the transmitted wave depends in a somewhat complicated way upon the speeds of propagation of the waves and the densities of the two media. Crudely speaking, the more nearly the second medium resembles the first medium, the greater will be the pressure amplitude of the transmitted wave and the smaller will be the amplitude of the reflected wave; however, as the second medium becomes distinctly different from the first medium in the product of its density and the speed of sound, the reflected pressure amplitude will become greater than the transmitted pressure amplitude. This knowledge is important when one wishes either to absorb sound energy or to reflect sound energy, and as subsequent speakers describe their subjects this fact will most likely become quite evident.

Methods of Defining a Noise Source

Turning now to the problem of how one defines a noise source, there are two commonly used methods. The first method describes the free field pressure radiation measured as a function of the angle of radiation from the source. Measurements using this method are normally made in the far field and represent the sound pressure radiated in various directions from the source under the condition that there are no reflecting surfaces in the vicinity of the source. Such measurements are commonly made in an anechoic chamber.

The second method leads to data which define the power radiated by the source. Measurements under this method are normally conducted either in a reverberation chamber or in a semireverberant room. Here the directional characteristics of the source are ignored, and the measurements yield only the total energy radiated. If one knows the free field radiation characteristics, the power of the source can be calculated; however, if only the power of the source is known, one cannot calculate the free field radiation characteristics.

The choice of method is made on the basis of the intended application. If one is interested in calculating the noise a machine will generate if it is placed in a room of known acoustical characteristics, then he should use the power definition. However, if one is calculating the effect of a machine as it radiates its noise toward a neighborhood, the free field pressure definition is generally most applicable.

In either case the measurements, whether they are sound pressure level or power level, are normally specified as a function of frequency. The most common way of specifying the frequency function is to supply data indicating sound pressure level in octave bands (or one-third octave bands) or sound power in octave bands (or one-third octave bands). It is conventional to use the decibel as the measurement of either sound pressure level or power level, but one must be careful to recognize that the reference levels for these two units are different. These reference levels will be discussed shortly.

The Sound Measurement Scale

Let us turn now to the physical measurement of sounds. Sound pressure is the attribute which relates to the amplitude of the sound, and frequency is the attribute which relates to the pitch of the sound. The range of sound pressures of interest to us is represented on the low end by the threshold of hearing of normal young people and on the upper end by the noise of small arms measured in the near field. Stated in physical terms, this sound pressure range is approximately from 0.0001 to 100,000 dynes per square centimeter (or microbars). (Atmospheric pressure represents 1,000,000 dynes per square centimeter.) It is clear that we are dealing with a tremendous range of sound pressures. Because in acoustics we are just as interested in observing the effects of small changes near the threshold of hearing as we are in observing the effects of small changes near the upper end of the scale, it would be impossible to construct a linear scale which would be applicable to our problem. An analogous problem which might be more meaningful would be one of measuring lengths where we are interested in having a scale ranging from one inch to 16,000 miles, and we need a ruler to measure changes of a few inches or changes of a few miles with the same ruler. The simplest mathematical scale available for either purpose is the logarithmic or decibel scale. One characteristic of the decibel scale is that it is possible to show, on an ordinary sheet of graph paper, a large range of sound pressures in such a manner that the small variations are as accurately portrayed as are the large variations. In my opinion this is the principal reason that the decibel scale is so useful in the field of acoustics.

Even though the decibel scale is a useful scale, it still creates many problems for the beginner and the uninitiated. I do not feel justified at this point in entering into mathematical definitions and calculations, but I shall try to give you some feeling for the units which you will hear and see in most, if not all, of the subsequent presentations. In our field of acoustics whenever the sound pressure level is designated in decibels, the reference level will be 0.0002 dyne per square centimeter (or microbar). On this scale zero dB sound pressure level corresponds to a pressure of 0.0002 microbar. A sound pressure level of 60 dB corresponds to a pressure not 60 times the reference pressure but 1000 times the reference pressure or 0.2 microbar. A sound pressure level of 100 dB corresponds to a pressure of 20 microbars, and finally a sound pressure level of 160 dB corresponds to a sound pressure of 20,000 microbars.

Sound-power level is also expressed in decibels, but here the reference level is 10^{-12} watt.[1] This means that a power level of zero dB represents a power of 10^{-12} watt. A power level of 60 dB represents a sound power of 10^{-6} watt; a power level of 100 dB corresponds to a power of 10^{-2} watt; and a sound-power level of 120 dB corresponds to a power of only 1 watt. These examples illustrate that for most of the sounds encountered in our daily lives the actual amount of power involved is less than 1 watt, which seems truly insignificant in comparison with our normal sources of power.

Frequencies and Their Relation to Sound Measures

The range of frequencies that concern us can be classified as the sonic range (20-20,000 Hz), the ultrasonic range (20,000 Hz and above), and the infrasonic range (20 Hz and below). The problems of hearing and noise exposure are normally associated with the sonic range; jet engines, ultrasonic cleaners, etc., are common sources which generate ultrasonic as well as sonic energy; and machines with parts which rotate very slowly, as well as large rockets, are common sources of infrasonic and sonic waves.

The specification of frequencies in acoustics is usually in frequency bands, although certain sounds such as the turbine whine of our jet aircraft engines will be specified as pure tones or a one-cycle per sec (Hz) bandwidth. The reason for using the larger bandwidths is that psychophysical experiments relating psychological response to physical stimuli have shown that very narrow-band subdivision by frequency of the stimulus is not especially meaningful in relating the psychological response to the physical stimulus. Clearly there are exceptions to such a generalized statement, as evidenced by pure-tone audiometry, but for the vast majority of the cases the general statement is a reasonable description of the situation.

Sound Measurement Equipment

During the presentations to follow, the physical stimulus will be described either in terms of sound pressure level or power level, and will be associated

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[1] An earlier reference was 10^{-13} watt, which is now superseded.

with a frequency scale which will vary from paper to paper. To interpret these data, both the method of measurement and the definition of the frequency range or scale must be clearly understood.

The most commonly used instrument is the sound level meter. If the sound is reported as having been measured with the sound level meter, the data will most likely be reported as sound level in dB or sound level in dBA. When the sound level is reported as dBA, the frequency range should be interpreted as approximately 400-10,000 Hz. If it is reported simply as sound level in dB, the measurements were probably made on the "C" frequency scale which covers a range of approximately 25-10,000 Hz. Unfortunately these frequency ranges are not as well defined as the numbers might indicate since the response of the sound level meter does not stop abruptly either below or above the frequencies which have been listed as the frequency range. Stated another way, the sound level meter has certain simple electrical circuits which provide a degree of frequency analysis of sounds. These circuits are referred to as "weighting networks" in that they give greater "weight" or importance to sounds in certain frequency ranges than in other frequency ranges. The labels associated with these networks are the "A," "B," and "C" scales. The A scale has an upper range of about 10,000 Hz and discriminates against frequencies lower than about 400 Hz. The B scale, which is seldom used, has about the same upper range as the A scale and discriminates against frequencies lower than about 125 Hz, whereas the C scale represents little or no discrimination over the frequency range of approximately 25-10,000 Hz.

It behooves anyone interested in acoustics to study in detail the response characteristics of sound level meters so that he may gain an appreciation of the meaning and implication of data taken with such a device. More and more data are being reported based upon sound level meter measurements, a trend that represents a significant change in our method of measurement. Beginning with World War II a very high percentage of all acoustical data were measured with acoustical instruments much more sophisticated in frequency discrimination than the sound level meter. Although the trend of sophisticated instrumentation still continues, the sound level meter is once again considered a useful instrument for the measurement of sounds.

Let us turn to those more sophisticated instruments just referred to. They fall under the generalized heading of "analyzers." The most common type is an octave-band analyzer. An octave is any frequency range in which the value of the upper frequency of response (f_H) is twice the value of the lower frequency of response (f_L). The octave analyzers commonly used before 1960 had such frequency limits as 75-150 Hz, 150-300 Hz, 300-600 Hz, etc. This older instrumentation defined the octaves in terms of their lower and upper cutoff frequencies. Beginning almost 10 years ago the method of designating the octave bands was changed from designating the cutoff frequencies as illustrated above to designating the center frequency of the band. Unfortunately, the center frequency of an octave band is not the arithmetic mean of the low and high cutoff frequencies but is their geometric mean. The geometric mean is equal to $\sqrt{f_L f_H}$, and since $f_H = 2f_L$, this makes the center frequency numerically equal to $\sqrt{2}$ times the lower cutoff frequency ($1.414f_L$). The center frequencies of the new octave analyzers start with 1000 Hz and extend up and down in frequency. If the center frequency is stated, a quick and reasonably accurate way of determining the low frequency cutoff is to multiply the center frequency by 0.7 which is equal to $\sqrt{2}/2$. The upper cutoff frequency of the bandwidth can then be calculated as two times the lower cutoff frequency. As an example, if the center frequency is 2000 Hz, the low frequency cutoff is $0.7 \times 2000 = 1400$ Hz; and the upper cutoff frequency is $2 \times 1400 = 2800$ Hz.

It is only natural that once the frequency domain was divided into octaves the next logical step would be to divide it into ranges of fractions of an octave. For a short period there was an "instrumentation struggle" between one-half and one-third octaves, but the battle was short-lived and the one-third octave analyzer was the victor. A one-third octave-band analyzer simply divides each octave into three one-third octaves. Thus an analyzer with 8 octave bands would now become an analyzer with 24 one-third octave bands. If one has data based on one-third octave band measurements, it is straightforward to calculate the octave-band data; however, it is not possible to calculate a one-third octave-band analysis from an octave analysis.

The development of all analyzers naturally follows the advances and capabilities of the electronics art, since the frequency bands are all obtained electronically within the analyzer. Recognizing this, one must accept the fact that in the competitive world of instrumentation other forms of analyzers will be developed according to the ingenuity of the people engaged in research. Manufacturers normally will wait until the market for new analyzers has been defined before embarking upon the development of commercially available products. This type of research and development has led to analyzers whose cutoff frequencies can be varied more or less continuously over wide ranges of frequencies. The size of the bandwidth will vary from one instrument to another, and it may or may not remain constant as a function of frequency. There are, in fact, two common types of narrow band analyzers: one called the constant bandwidth analyzer and the other a constant percentage bandwidth analyzer. A constant bandwidth analyzer has a passband which is constant and independent of the center frequency of the passband. A 10-cycle bandwidth analyzer would imply that if the center frequency of the passband is at 200 Hz the bandwidth would be 10 Hz, and if its center frequency is at 2000 Hz the bandwidth is still 10 Hz. On the other hand if the analyzer were a 10% constant percentage bandwidth analyzer and the center frequency is at 200 Hz, the bandwidth would be 20 Hz. If, however, its center frequency were at 2000 Hz, the bandwidth would be 200 Hz. It is relatively easy to explain the mathematical relationships just given, but the effect on the data obtained using these two types of analyzers is not as easy to explain.

It must be understood that the output indication of any analyzer depends upon the bandwidth of the analyzer. If one therefore measures the same sound with an octave-band analyzer, a one-third octave-band analyzer, a 10-cycle constant bandwidth analyzer, and a 10% band analyzer, the data obtained with these four analyzers would differ significantly from each other even though the noise measured is identical. If these four analyses are displayed on the same graph, the four spectral curves will be different. An untrained observer might therefore think that there were four different noises, whereas the sophisticated person would recognize these four spectral curves as representing the same noise, provided sufficient information is shown on the graph to indicate the type of instrumentation used to obtain each of the four spectra.

It is clear that as one divides the sound energy into various size frequency bands, the energy in a particular frequency band cannot equal the total energy in the sound. If a sound has equal energy in every cycle (this is called white noise), a little thought will convince you that as the bandwidth becomes more and more narrow, the output of the analyzer will decrease accordingly.

Equipment Limitations. Up to this point I have not concerned myself with the method of displaying the output of noise measuring instruments. Most of you are aware that the common form of output registration is a simple meter. Data are secured by recording the deflection of the meter needle in terms of the scale on the meter, and this deflection is normally combined with the setting of a control or controls associated with the instrumentation. In most cases these controls move in fixed steps of 10-dB intervals.

The point to be stressed is that the mechanical and electrical characteristics of the indicating meter itself cannot be disregarded. If the sound is more or less steady, the characteristics of the meter have well-defined effects upon the deflection of the meter needle. If, however, the sound changes in intensity rather quickly with time, the effects of the meter's characteristics can no longer be well defined. The meter movement does not respond to alternating current (AC) signals but is responsive to direct current (DC) voltages; hence, the AC signal which corresponds to the acoustic signal must be converted into a DC signal before being applied to the output meter. The needle of the output meter can respond to changes in the DC voltage, but not if these changes take place in a time shorter than about 0.2 sec. As a consequence, the use of conventional sound level meters and analyzers must be restricted to steady types of noises or to steady noises that are not rapidly interrupted.

To measure noises which change rapidly with time (impulse noises) special attention must be given to the entire system, i.e., microphone, amplifier, and output indicator. Consider two types of impulse sounds, the first being the noise generated by a rifle being fired and the second being the noise generated by a drop-forge hammer. These are both classified as impulse sounds, but clearly the duration of the noise from the rifle will be very much shorter than the duration of the noise from the forge. Because of this, the instrumentation which would be acceptable for measuring the forge noise will not necessarily be acceptable for measuring the gun noise.

This last statement needs an explanation. The customary way of specifying the performance of a measurement system is to state the frequency range for which the response is uniform. Seldom is equipment rated for its range of rise times; however, a simple engineering rule of thumb can be explained which relates rise time to frequency response. Consider an acoustic system responding to a 1000-Hz signal (1000 Hz is chosen only to make the arithmetic easy). The sound pressure fluctuates about the normal atmospheric pressure in such a manner as to produce a compression and a rarefaction in 1/1000 sec (i.e., the wave has a period of one msec). Remembering the shape of a sine wave, one can see that the system responds to a change in sound pressure from atmospheric to maximum compression in ¼th of the period or in ¼th msec. This can also be thought of as the "rise time" of the sine wave. Put another way, a 1000-Hz signal might be thought of as having a rise time of ¼th msec.

Suppose a measuring system was quoted as having a uniform frequency response up to 1000 Hz. (This upper frequency of response is commonly referred to as the "cutoff frequency.") If the upper limiting frequency of this system is 1000 Hz, it is evident that the system could not respond correctly to changes that take place in less time than ¼th msec. Thus frequency response can be related to rise time response.

Since impulse sounds from guns have rise times of the order of a few μsec, proper measurement requires a system able to respond to rise times even shorter than a few msec. Suppose the required rise time response is one μsec, which corresponds to the rise time of a pure tone of 250,000 Hz. The upper cutoff frequency of the system then would have to be at least as high as 250,000 Hz. If the rise time to be measured were shorter, the upper cutoff frequency would have to be still higher.

It should be evident by now that to measure gun noise requires special equipment. Microphones that are most suitable for this type of system are the very small (1/8 in diameter) condenser types or ceramic types. High quality amplifiers and oscilloscopes with microsecond sweep rates make up the remainder of the system. Photographic recording of the oscilloscope wave pattern is the usual form of output registration.

Returning to our comparison of gun and drop-forge noise, the measurement of drop-forge noise does not require a system with the extended high-frequency response required to measure gun noise since the rise time of the pressure wave for the forge noise is much longer than is the case of gun noise. For the drop-forge measurement, a high quality microphone and amplifier (response uniform to 15 or 20 kHz) would be satisfactory, and all that would be necessary would be to use an oscilloscope as the output indicating device. The microphones and amplifiers of most high-quality sound level meters would be acceptable, but their indicating meters would be unacceptable since they cannot respond to such rapid changes, as was pointed out earlier.

When measuring gun noises where the frequency response of the system must extend to such very high frequencies, it should be remembered that the wave lengths of these acoustical signals are very short. Since this is the case, many subtleties arise in positioning the microphone and in making the measurements. It is sufficient to say that the measurement of such impulse noises should not be undertaken by someone unless he is very well grounded in physical acoustics.

Recently the sonic boom has become a topic of national interest. Since this sound falls within the definition of an impulse sound, it follows that instrumentation for the measurement of sonic booms is sophisticated and in certain cases quite complex and so the comments concerning gun noise measurement also apply to the measurement of sonic boom noise.

It may not have been obvious, but the discussion on method of data display changed significantly when the topic shifted from the measurement of steady-state noise to impulse noise. Measurements of steady-state noise normally yield amplitudes as a function of frequencies. Mathematical techniques developed by Fourier and Laplace show that it is possible to represent a time-varying signal such as sound in at least two ways. Amplitudes may be shown as a function of frequency or as a function of time. It is possible to compute one relationship if the other relationship is known. The form of representation is normally dictated by the sound under investigation. In the case of impulse sounds, it is more convenient to represent the amplitude as a function of time rather than to show the amplitude as a function of frequency. The impulse noise generated by rifle fire usually produces a very rapid compressional rise to a peak, followed by a relatively slow rarefaction wave. The most relevant pressure value in this type of noise is probably the peak pressure of the initial compression. On the other hand, a sonic boom has a time pattern with more of the appearance of a stretched out "N." In this case, the pressure value most commonly referred to represents the pressure difference between the compressional peak and the rarefaction peak, a measure sometimes referred to as peak-to-peak sound pressure. As the various speakers present their papers, I am sure you will observe the many forms of presentation of physical data associated with the noises under discussion.

Physical Measurements in Noise Control

Concerning the physical measurements related to noise control, there are four major concepts I would like to define, namely: *absorption coefficient, reverberation time, transmission loss,* and *noise reduction.*

The absorption coefficient of any material represents the ratio of absorbed energy to the energy incident upon the material. If the material is a perfect reflector, the absorption coefficient is zero; and if the material is a perfect absorber, the absorption coefficient is one. Absorption of sound is accomplished by generation of heat which results from the movement of air particles against the surface of the absorbing material. In any material, the more surface exposed to air movement the greater will be the absorption. From a materials point of view, the design objective for high absorption is to produce a fiber of very small diameter so that within a given volume many more fibers can be packed and hence much more rubbing surface area can be exposed to the air.

Thus the two principal ingredients are (1) the exposure of a large amount of surface area to the sound; and (2) the movement of air within the volume occupied by the material when the sound wave strikes the material. This latter requirement is often forgotten, and it accounts for the fact that even though a material exposes a large amount of surface area, it may not be an efficient absorber. This is especially the case when 1 or 2 in. of absorbing material is attached directly to a massive wall. As sound strikes the wall it is almost totally reflected due to the large difference between the speed of propagation of sound in the massive wall material compared with the speed of sound in air. As a result of this very efficient reflection, a pressure maximum is associated with the surface of the wall. Also since the wall is massive and does not move, the particle velocity at the wall is minimum. The nature of compressional wave motion is that a velocity maximum occurs at a location one-fourth of a wavelength removed from a velocity minimum. If a low frequency sound, say 125 Hz, strikes the wall, the particle velocity at the wall will be essentially zero. Since the wavelength of a 125 Hz signal is approximately 10 ft, the maximum particle velocity will occur at a position approximately 2½ ft (one-fourth of a wavelength) away from the wall. Thus the particle velocity of the air within a distance of 2 in. of the wall will of necessity be very small; hence the absorption will be low. If this same 2 in. of material is spaced out away from the wall the particle velocity will be greater and thus the absorption by the material will be greater. If one wishes to have a high absorption coefficient for low-frequency sounds the depth of the absorptive material must be great or the material must be spaced out away from the wall. This is one of the major problems in absorbing low frequency sound.

Reverberation is a term which the layman intuitively feels he understands. Technically, the reverberation time of a room is the time required for any sound to decrease in amplitude by 60 dB if the sound source is turned off and the sound allowed to decrease by virtue of absorption within the room. If the room has very little absorption (if all of the surfaces are acoustically hard), a greater length of time will be required for the sound to dissipate in the form of heat and hence the longer will be the reverberation time; if the absorption within the room is great, the reverberation time is shorter. From the standpoint of noise control, the problem is usually not how long a time is required for the sound to diminish 60 dB after the source is turned off, but what is the sound pressure in the room while the source is operating. This is similar to the concept of power available from a source, discussed earlier. As the source continues to operate and radiate sound, part of this radiated sound will be absorbed and eventually a condition will exist where the amount of energy radiated equals the amount of energy absorbed and the sound pressure within the room will reach its steady-state value. It follows, therefore, that the greater the sound absorption within the room the lower will be the steady-state sound pressure with a sound source such as a machine operating. Thus the reverberation time of a room is measured not for the purposes of decay of sound but for the purpose of determining the average absorption characteristics of the room. Once these are known and once the sound power radiated by the source is known, the sound pressure levels generated in the room by the source can be calculated. Incidentally, these sound pressure levels cannot be calculated from pressure measurements made using the same machine operating in another room unless the absorption characteristics of this second room are also known.

Normally part of the problem of noise control is how to prohibit sound from traveling from one room to another. A wall separating a room containing a noise source from a room desired to be quiet can be characterized by its transmission loss (TL). Transmission loss is a property of the wall itself, and is defined as the ratio of the energy transmitted through the wall to the energy striking the wall. To measure the transmission loss of a wall, a noise source is placed in a reverberant or semireverberant room, one wall of which is the wall under test. On the other side of the wall under test (the receiving room) there may be complete absorption by all of the other wall surfaces (an anechoic chamber) or there may be another semireverberant room. Since sound pressure levels rather than energy levels are measured in both rooms the data must be corrected on the basis of the size of the panel under test and upon the absorption characteristics of the receiving room. These corrections are necessary for the determination of the transmission loss of a wall, and it must be kept in mind that the TL values listed for a wall structure relate to the transmission of energy. Energy transmission and sound pressure transmission are not the same thing.

In actual problems of noise control, the sound pressure levels are of much greater interest than are energy levels. The "real world" problem is to reduce the SPL of the noise in the receiving room. The difference in the sound pressure levels in two rooms separated by a wall is defined as the noise reduction (NR) in decibels of the wall. Thus a particular wall will have TL values that differ from NR values because the NR values are functions of the wall and the room. The analogy to electrical transmission problems is that sound pressure corresponds to voltage and in the transmission of electrical energy voltage may increase or decrease depending upon the impedance across which the voltage is measured. Voltage and power do not always change in the same manner. Thus NR values may be greater or less than TL values depending upon the wall size and the absorption in the receiving room.

If one knows the TL values of the wall and the reverberation time of the receiving room, the sound pressure levels in the receiving room can be calculated provided the sound pressure levels in the source room are known. The problem of noise control resolves itself into knowing the sound power of the source and the reverberation time of the source room in order to calculate the sound pressure level in the source room, and knowing the TL values of the wall and the reverberation time of the receiving room the sound pressure levels in the receiving room can be determined. One normally increases the efficiency of a wall as a sound barrier by making its TL value smaller and smaller, i.e., the less energy which gets through the wall the smaller the TL value. This implies that more sound is reflected by the wall back into the source room, and to achieve this phenomenon there must be significant discontinuities of speed propagation in the wall with respect to the speed of propagation of sound in air as well as large density discontinuities. Since TL values are less than unity, the dB values of TL are negative; however, it is common practice to omit the negative sign and refer to the dB values as the amount of wall attenuation.

Recently it has been agreed that a single rating of walls can be stated in such a way as to make it meaningful. It is obviously of little use to know the average value of TLs measured at frequencies covering the range of interest since the average value provides no insight as to whether the wall is "good" at certain frequencies and "bad" at other frequencies. Just as knowledge of a sound spectrum (amplitude vs frequency) is important, so is the knowledge of TL versus frequency for a wall important. The new single classification of rating walls is called "sound transmission class" (STC) and relates to the frequency characteristics of a wall. Frequency contours of TL have been agreed upon and in general these TL values, in decibels, rise from 125 to about 350 Hz at a rate of approximately 10 dB/octave and then change to a rate of about 3 dB/octave for frequencies of 350 Hz to 1500 Hz and remain uniform with frequency above 1500 Hz. The STC rating of a wall is given as the uniform (flat) value of this frequency contour for the higher frequencies. Thus a wall with an STC value of 45 dB has transmission loss values (actually attenuation values) which equal or exceed the frequency characteristics of the standard contour which carries the "45 dB" rating. Measurements of TL values are made using one-third octave bands of noise rather than pure tones.

Psychophysics

Turning now to a new but allied subject, the field of psychophysics relates the psychological response of humans to physical stimuli. The word "psychoacoustics" is sometimes used to describe the field if the stimulus is sound. In general, man serves as part of the experimental apparatus and his response—oral, written, or some other—is based upon his psychological judgment of the attribute under study. Some measure of his psychological response must be developed in order to quantify the relations between the physical stimulus and the psychological response. For our purposes there are three such psychological terms which need definition: *loudness level, loudness,* and *noisiness.*

Loudness level is a hybrid term and does not represent a true psychological unit of measure. It involves a psychological judgment but it is also characterized by a physical measurement of sound pressure level. By definition, *loudness level* is the sound pressure level of a 1000 Hz pure-tone stimulus that has been judged to be equally loud as the stimulus to be defined. Thus if the loudness level of a noise is to be measured directly, subjects must be asked to equate the loudness of a 1000 Hz stimulus with the noise. Once this equality has been established the sound pressure level of the 1000 Hz signal is measured and this level, expressed in phons (equal, for the 1000 Hz tone, to the sound pressure level in dB), becomes the loudness level of the noise.

Of more interest to psychophysicists is the matter of the true loudness of the noise. *Loudness* is a psychological measure, and it has been scaled by a number of experimenters. The experiments of S. S. Stevens and E. Zwicker dominate the literature dealing with this subject, and the methods developed by these experimenters are the only ones in general use by people in the field. The unit of loudness is the *sone*. The sone is arbitrarily tied to the physical scale by setting the value of the loudness of a 1000 Hz signal of 40 dB SPL (also 40 phons) as having a loudness of one sone. All other loudnesses are obtained by psychophysical judgments following the techniques of Stevens and Zwicker. Their techniques are similar in many respects but their methods of calculation differ principally in their interpretation of the effects of inhibition which takes place when humans listen to sound and judge its loudness. Each procedure has its camp of followers, and you will hear experimenters refer to "Stevens sones" or "Zwicker sones." For the purposes of this particular meeting it is my feeling that you can forget the subtle differences between these two procedures and accept the fact that from an engineering point of view we are in a position to calculate the loudness of a sound if we know its octave or one-third octave spectrum.

The advent of commercial jet airplanes spurred investigations to establish the relative acceptability of the noise of jet aircraft compared with the noise of propeller aircraft. Research in this field led to the development of the concept of *noisiness.* The unit of noisiness is the *noy*. The development of the noisiness scale paralleled the procedures used by Stevens in developing the loudness scale. The noisiness in noys, or the perceived noise level in PNdB, is principally associated with the name of K. Kryter. The perceived noise level, expressed in a decibel form as PNdB, represents the noisiness on a logarithmic scale rather than on the linear scale of noys. The details of how one calculates the PNdB value of a noise are not important at this point; but it is important to understand that if the octave or one-third octave spectrum of a noise is known, one can calculate, by similar procedures, the loudness in sones, the loudness level in phons, the noisiness in noys, or the perceived noise level in PNdB. These values may differ somewhat for the same noise spectrum; but as long as one restricts noisiness to airplane-type noise, Kryter feels there is a significant difference between noisiness and loudness and that these two concepts are not the same. I think it only fair to point out that other people in the field share a feeling that the concept of noisiness may not differ significantly from loudness over a wide range of noise characteristics. Research in this area has not been extensive enough to decide the matter one way or another. At present it would seem best, in my opinion, to limit the application of the noisiness concept to jet aircraft and propeller aircraft noises.

Miscellaneous Terminology

Several other terms will probably appear during the course of this Conference and should be defined. One of these is *speech interference level* (SIL). Many problems of noise control are related to establishing an environment conducive to carrying on conversation by individuals separated by conventional distances and speaking in normal levels of speech. It has been shown that the masking noise which lies within the frequency range of approximately 500 to 5000 Hz is important in determining the masking effect of the ambient noise in terms of speech. The original psychophysical work related masking to the average sound pressure levels measured in the three octave bands: 600-1200, 1200-2400, 2400-4800 Hz. The numerical average of the dB values per octave in these three octave bands is defined as the speech interference level. In terms of the new octave designation by center frequencies, the corresponding SIL value is the average sound pressure level measured in the 1000, 2000, and 4000 Hz bands. The term SIL can also mean the average SPL in the 500, 1000, and 2000 Hz bands.

Criteria for various types of environments such as offices, libraries, and theaters have been developed in several countries. The result is a series of sound spectra contours extending over a wide range of sound pressure level values. These curves have been defined as Noise Contours (NC) and are extremely useful in many aspects of noise-control work. An acceptable NC contour for a given space will permit a spectrum which decreases in sound pressure level as the frequency increases; that is, more low frequencies are permitted than high frequencies. Spectral ranges have been established for a wide variety of everyday activities, and these criteria are published in the standard textbooks and in the scientific literature.

A few closing comments must be made concerning the terminology which you will hear used in connection with various criteria where the stimulus, as related to the noise criteria, will inevitably be given in terms of *noise exposure.* It must be recognized that noise by itself is not the total stimulus which is used to establish criteria, but it is the combination of noise and exposure time that is important. The manner in which noise levels and time are combined results in a noise exposure variable. The methods of combination differ depending upon the subject.

In much the same way, the measurement of the human response depends upon the subject. If the problem is damage to hearing, the measurement of hearing is, at present, performed by pure-tone audiometry. The pure-tone audiometer determines the sound pressure level at various frequencies at which the subject just hears the pure tone. The difference between the threshold level for the individual being tested and the accepted normal threshold level for young individuals is the measure of the hearing threshold shift at that particular frequency. If this shift is a temporary one, the difference is referred to as temporary threshold shift (TTS); however, if this threshold shift is stable with time, it is referred to as a permanent threshold shift (PTS). For airport noise problems, the measure is the "annoyance" or the "complaint" level of the community. In other cases speech interference level is the measure —and so it goes.

It is inevitable that within the short period of this presentation certain terminology which should have been defined and discussed will have been omitted. An attempt has been made to cover the major topics in terms of their terminology, their concepts, and their definitions. It is my hope that this presentation will make it easier to understand the many papers to follow.

Panel I
Effects Of Noise On Man

Opening Remarks

Karl D. Kryter, Panel Chairman

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The task of the first panel of this Conference is to provide a meaningful description of some of the basic effects of noise on man and to relate these effects to fundamental psychological and physiological factors that might help to give us an understanding of these effects. This general topic can be divided into the following three broad areas: (1) the effects of noise upon man's auditory system; (2) the subjective, psychological effect of noise; and (3) the effects of noise on man's nonauditory systems. I will discuss briefly each of these topics.

Effects of Noise on Man's Auditory System

Researchers concerned with noise problems have directed their attention mainly to the question of hearing loss resulting from intense industrial and military noise. This is as it should be inasmuch as the auditory system is so much more sensitive to sound than any other structure or organ in the human body, so much so that, at least for airborne sound frequencies from 20 to 20,000 Hz, it appears that the ear will suffer irreparable harm before the nonauditory systems of the body are adversely affected or, for the most part, even stimulated.

In spite of the great amount of research attention this problem has been given, there are a number of unanswered specific questions that await answers from painstaking research with humans and animals. Nevertheless, the state of knowledge on this problem has reached the stage where this knowledge can be applied with a considerable degree of confidence in the specification of tolerable exposure conditions for a tremendous variety of noises. Two of the reasons it has taken so long—more research remains to be done—to reach the understanding presently available on this problem are the following: (a) until relatively recently electronic instruments were not available for the physical measurement of noise in ways that simulated, with some degree of fidelity, the capability of the ear to respond to noise, and (b) the ear, while a tremendously sensitive organ, is, at the same time, a very complex and tough one.

A second fundamental effect of noise on man's auditory system, and not unrelated to auditory fatigue or damage to hearing, is that noise engages the auditory system in ways detrimental to the reception and analysis of more wanted sound signals. While the damage to the auditory system is deplorable, the temporary interference by noise with the proper functioning of the auditory system during man's daily work and social activities is, from a practical point of view, perhaps more important and causes more suffering. This, too, is an area that has received its share of research attention: as a result the understanding of masking, particularly the masking of speech by noise, has reached a very sophisticated level; indeed, it has reached the level where one can start simplifying and generalizing what is known about masking without too much fear of being surprised at some phenomenon related to speech reception in the presence of noise.

Effects of Noise on the Psychological State

This is an area where the effects of noise are hard to define. The research methods for studying psychological effects of noise reflect some of the uncertainty as to what these effects are and how to go about measuring them. There is a strong and perhaps unwarranted temptation to apply the concepts and information obtained in the laboratory about the basic psychological attributes of sound to the more complex relationship between noise, as unwanted sound, and man's psychological state of mind in the real world: New research methods and approaches must be developed.

It is obvious that the rich variety of man's sound-noise environment and the individual differences in personalities of people make the quantitative description of possible relationships between the hard measures of the physical attributes of sound to man's psychological states a most challenging task. But if man is to improve his general environment, it is an important and pressing problem.

Perhaps the problem can be clarified if it is understood that, for noise control and noise engineering purposes, one deals with these problems in a statistical way. We are interested in the "average" man with, of course, some due recognition of variability. It is a socially accepted fact that the unusual reactions to everyday noise by individuals or the rare occurrences of a given type of noise must be ignored as a matter of environmental noise control when the effect involved is one purely of "psychological state." In a sense, the problem is to determine the relationship between the physical attributes of sound and man's psychological state or reaction to them only when man is engaged in those activities of primary importance to him and which occupy the larger share of his life. It is possible that the unacceptability of noise will be sufficiently related to the physical aspects of noise, for such common and important attributes as masking of speech, loudness, perhaps general unpleasantness, distractiveness, auditory fatigue, etc., that a single environmental noise measurement procedure will be practicable. Further, it might be envisaged that rather than test separately, by various means, each relative effect upon the average man's general psychological state and general reaction to a given noise environment, it may be worthwhile to ask man to consider, when rating noises, all of these effects simultaneously, imposing his own particular value judgments during the process. Whether man can do this in a useful way is an empirical question that to some extent has been answered in the affirmative.

If man makes these ratings and then behaves in real life in a way consistent with these ratings or judgments, we must conclude that, practically speaking, our evaluation procedures and subjective rating scales are reasonably valid and useful. Again, the concepts of the average man and the improvement or control of the average environment are of paramount importance. It is to be hoped that some generalization on relationships between psychological states and physical variables in sound will be possible; otherwise the general control of noise environments will remain a very difficult task.

Effects of Noise on Man's Nonauditory Systems

As mentioned before, the ear is the primary receptor for sound and, with a few exceptions, the way in which sound gets introduced into man's nervous systems. However, man's response to sound can be extremely complex, as we know, and can involve, directly and indirectly, many physiological mechanisms. It has become increasingly clear that some of these secondary physiological effects of noise on man are measurable, and of possible importance to his behavior and health. Because of rather subtle and small responses to noise by nonauditory systems, compared with the responses of the auditory system, it has been difficult to demonstrate or elucidate these effects, or to distinguish them from effects possibly caused by factors other than noise.

This problem area represents a frontier of research in the field of the effects of noise on man. One of the key questions is not whether there are or are not nonauditory physiological effects of noise on man, but whether these effects will eventually harm man. This question has received much more attention in Europe than in the United States and, indeed, much of the knowledge available on this subject is to be found in the works and papers of Jansen and Grandjean. I think, however, that in the future we will see a greater interest and concern in the United States on the questions of the general physiological and health reactions of man to noise.

Effects of Noise on Hearing Thresholds

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Noise affects the ability of an organism to detect weak signals both while it is present and afterwards, the latter usually on a temporary, but, under some conditions, on a permanent basis. The concomitant change in threshold sensitivity is commonly called *masking.* Webster will discuss such interference, when the signal to be detected is speech, in his presentation. Masking, however, is of course not limited to speech. For example, danger signals may become undetectable; if one intends to cross a street near where a worker is tearing up the sidewalk with a jackhammer, he should be careful to use his eyes even more than usual, because he might not be able to hear an approaching truck until too late. One can hardly deny that this would represent a distinct health hazard.

However, effects of this nature are not my topic here. The diminution, following exposure to noise, of the ability to detect weak auditory signals is termed *temporary threshold shift* (TTS) if the decrease in sensitivity eventually disappears, and *NIPTS* (noise-induced permanent threshold shift) if it does not. For years it has been assumed that these two phenomena were very closely related: (1) that noises that produced equal average amounts of TTS (sometimes called *auditory fatigue*) would also produce equal amounts of NIPTS; (2) that if one noise produced twice as much TTS as another, it was also twice as dangerous in regard to NIPTS; and (3) that if one individual showed half as much TTS as another, he would suffer only half as much permanent loss. The notion seems to have originated with Temkin in Russia in the late 1920s, since Peyser mentions him (though with no bibliographic reference) in the first article to propose a test for individual differences in susceptibility to damage from noise that consisted of measuring the TTS produced by a short exposure to a high-frequency tone (Peyser, 1930).

Now auditory fatigue in all its aspects—not only the temporary shift of threshold but also correlated phenomena such as shifts in pitch, loudness, and timbre of suprathreshold stimuli (diplacusis, recruitment, and distortion); disappearance of a sustained tone that is initially above threshold (tone decay); ringing in the ears (tinnitus); and changes in the lateralizing power of a monaurally-presented tone as its duration increases (so-called perstimulatory fatigue)— is to some of us quite fascinating in its own right. Information about these phenomena is, we feel, important to an eventual understanding of the normal mode of operation of the auditory system. We shall therefore in all probability continue to ask for funds to continue research in the area. However, recent experiments have cast some doubt on the assumption that TTS and NIPTS are actually as closely related as previously thought.

In all fairness to the proposition that TTS and NIPTS are isomorphic in man, it must be admitted that it has never been tested directly. No one has ever selected a group of normal-hearing individuals, subjected them to a wide variety of TTS tests, and then exposed them under controlled conditions to noise so high in intensity that large amounts of NIPTS were produced. Although a few studies have involved presentation of a single TTS susceptibility test which was followed later by measurement of NIPTS produced by the intervening industrial noise exposure, the assumption that all the men in the test group received even approximately the same noise exposure at work was generally no more than a case of wishful thinking. Furthermore, in some studies the measured NIPTSs were so small as to be insignificant; postulating on the basis of evidence such as this that individual difference in TTS are not predictors of PTS represents a curious use of logic (e.g., Sataloff et al., 1965).

Since we cannot determine the relations between TTS and PTS in man, we must use experimental animals for which exposures can be controlled, assuming that what is true for the monkey, the dog, the guinea pig, or the chinchilla is also true for man. We have just completed a study in which 20 chinchillas were given a number of susceptibility tests involving short exposures to a moderate-intensity noise, and then were partially deafened by a 2-hr exposure to the same noise at a higher level. We observed no statistically significant correlation between TTS and PTS (Ward and Nelson, in press). Apparently the characteristics most important in determining whether or not an ear will get a relatively large amount of TTS are not also those that determine the degree of final loss from a particular exposure, even when the spectrum of the noise is constant.

This conclusion may not be too surprising, in view of the complexity of the hearing mechanism. It does, however, force us to be wary in assuming that the laws governing the growth and recovery of TTS are applicable to PTS. The burden of proof, that is, is definitely on the affirmative.

Nevertheless, known relations specifying the effect of various characteristics of noise on TTS constitute just about the only evidence that supports inferences about the relative noxiousness of different noise exposures in regard to NIPTS. Such relations have in fact been used in deriving the recent damage-risk criteria (Kryter et al., 1966) to be discussed by Eldredge and Miller in the next panel.

The most firmly established relations between noise and TTS are these (Ward, 1963):

(1) The growth of TTS in dB is nearly linear in the logarithm of time. Such an exponential course may be analogous to the photoreceptor processes in the retina that account for the phenomena of light-adaptation. Moderate

TTS also recovers exponentially in time, recovering completely within 16 hrs after exposure. However, when the TTS has reached 40 dB or more, recovery may become linear in time, with the TTS requiring days or even weeks to disappear. This 40 or 50 dB of TTS may represent some sort of "critical TTS" that should not be exceeded if danger of permanent damage is to be avoided.

(2) Noises whose maximum energy is in low frequencies will produce less TTS than those whose energy is at higher frequencies. That is, a rumble is less dangerous than a screech.

(3) The maximum effect from a noise that has energy concentrated in a narrow frequency range will be found half an octave to an octave above that range rather than at it.

(4) TTS increases linearly with the average noise level, beginning at about 80 dB SPL, at least up to 130 dB or so. In other words, the difference between TTSs produced by 100- and 110-dB noises will be about the same as the difference between those produced by 110 and 120 dB.

(5) An intermittent noise is much less able to produce TTS than a steady one. In fact, the TTS is proportional to the fraction of the time that the noise is present. A noise that is on only half the time (in bursts of a few minutes or less) can be tolerated for much more than twice the number of working hours that could be spent in the noise when continuous, before the same TTS would be produced.

(6) Neither growth nor recovery of TTS is influenced by drugs, medications, time of day, hypnosis, good thoughts, or extrasensory perception. The locus of the physiological deficit associated with TTS thus seems to be extremely peripheral—at the hair cells of the cochlea, to be specific.

We certainly hope that these general, average relations for TTS also hold for PTS, even though individual differences in TTS and PTS do not seem to be correlated. Indeed, the most recent damage-risk criteria assume that the laws governing the average will be as true for NIPTS as for TTS. However, it will be some time before the necessary experiments can be performed. At the present time, therefore, one could argue that things have really not improved much since 1914, when Peyser summarized a 50-page review of occupational hearing loss with these words: "Ueber den wirklichen Umfang der gewerblichen Hoerstoerung wissen wir aber bisher nichts" (Peyser, 1918). Peyser blamed faulty statistical procedures for this lack of knowledge, and urged a central repository for all industrial hearing-loss data. So, two generations later, permit me to reiterate his contentions, as I attempt to summarize our present knowledge about NIPTS.

First, however, it is necessary to distinguish two terms that in most studies and surveys dealing with the effects of industrial noise are hopelessly intermingled with NIPTS: presbycusis and sociocusis. *Presbycusis* is a loss of high-frequency hearing associated with the physiological aging process; presumably it would proceed at the same rate whether noise were present or not.

Audiometric data involving workers over age 60 or so will be "contaminated" to some degree by this process. *Sociocusis,* however, is not dependent on age per se. Instead, it is loss of hearing attributable to noxious influences other than the noise associated with the individual's employment. That is, PTS produced by outboard motors, chain saws, tractors, sporting arms, and blows to the head would be called sociocusis except when they occur in a northwoods guide, a forester, a farmer, a safari leader, and a boxer, respectively. In those individuals it would be called NIPTS for purposes of compensation. PTS resulting from illness would be sociocusis for anyone.

The concept of sociocusis arose in connection with the analysis of average results of audiometric surveys (Glorig and Nixon, 1962). It was found that even in persons with no recallable history of exposure to high-intensity noise, gunfire, or head blows, the average hearing gradually decreased with age even before age 60 (i.e., before presbycusis could enter the picture). The hypothesis was therefore advanced that this average loss of hearing represented the toll exacted on a few individuals by the everyday noises of modern living.

This is not to say, however, that everyone gets a small amount of hearing loss from such noises, so that it becomes legitimate to subtract from an individual's hearing loss the sociocusis the average man (not exposed professionally to noise) would have had at his age. Although such a correction for sociocusis (plus perhaps one for presbycusis) can be justified over the long run on actuarial grounds, in the individual case it is about as nonsensical as, for example, giving a guaranteed minimum salary to everyone, helping not only those who are willing to work but also those who are unemployed because of laziness. In the individual case, a hearing loss was either caused or aggravated by sociocusic influences or it was not. Of course, it is not always easy to determine this after the fact, hence sociocusis-plus-presbycusis "corrections" will no doubt continue to be made. However, the chief value of the concept of sociocusis, in my opinion, is that its recognizance keeps one from quickly attributing a given hearing loss to the worker's noise environment without probing deeply into possible sources of hearing loss in the man's extra-industrial past. The whole problem of whether or not to apply a sociocusis correction would be largely eliminated if all employers would require pre-employment audiograms of each worker, together with regular follow-up tests every year. One would then not always need skill somewhat superior to that of Sherlock Holmes in order to estimate the probable cause of a given hearing loss. Again, however, most employers fear that institution of such procedures will stir up trouble, so they should "let sleeping dogs lie," etc. This can be called the "ostrich" or "head in sand" syndrome, in view of the fact that compensation boards almost invariably put the burden of proof on the employer: if a worker has a hearing loss, it is up to the employer to prove that his noise was not responsible. And this, it should be clear by now, is most difficult.

The only sure way to establish this, outside of showing that the employee entered the noise with the same hearing loss, is to be able to demonstrate that the noise produces no loss in anyone. In this case, average procedures do have value, because they allow us to make such a categorical statement with some confidence. Baughn (1966) has shown, in an analysis of 6835 audiograms, that when the level of the noise is below 80 dBA (80 dB on the "A" scale of the sound-level meter, a scale that, as Rudmose has indicated, discounts the effects of low frequencies, which are not quite as dangerous, decibel for decibel, as higher frequencies), the incidence of compensable hearing loss is no greater than in a non-noise-exposed population of the same age and general socioeconomic status. (Compensable losses are those so severe as to cause an appreciable decrement in the ability to understand ordinary speech; at the moment, the dividing line is an average Hearing Level of 25 dB at 500, 1000, and 2000 Hz, relative to the new ISO audiometric standard.) Botsford (in press) has gathered together this type of industrial data from several sources; these data imply that for relatively steady 8-hr daily exposures, about twice as many individuals show compensable losses after years of exposure as one would find in a group of men not exposed to industrial noise at all (or to 80 dBA, which is the same thing as silence). Thus when the worker's noise environment is below 80 dBA, the probability is zero that the noise caused his hearing loss; when the level has been 95 dBA, the probability is about 50%. At 105 dBA, steady continuous exposure produces losses in nearly all men who are habitually exposed. Just where to draw a line to protect hearing is the problem of damage-risk criteria, the topic to be discussed later today.

In this report I cannot cover in detail all the facts or even all the old wives' tales about NIPTS. However, let me mention briefly some of the more important questions.[1]

1. *Are certain frequencies more sensitive than others to damage from noise?* After long exposure to industrial noise or, for that matter, to gunfire, the frequencies showing first and most severe NIPTSs are those in the vicinity of 4000 Hz, with neighboring frequencies affected later. The reason for this seems to be a combination of two factors, according to Lehnhardt (1966, 1967): (1) the middle ear transmits the frequencies between 1000 and 4000 Hz most efficiently, so that more energy reaches the cochlea in this range; and (2) a given area of the basilar membrane is affected by a wide range of frequencies below its characteristic frequencies, but not by those above; therefore all of the most intense noise elements affect the 4000-Hz receptors.

2. *How long must the ear be out of noise before it will have recovered all it is going to?* Two weeks is mandatory (Atherley, 1964) but little further recovery occurs after a month, although occasionally, following trauma from a single incident (such as a firecracker exploding near the ear), slight additional recovery may occur in the second month. In Wisconsin a 6-month noise-free period is required, but this regulation is based more on political than scientific grounds.

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[1] For an up-to-date detailed review, the monographs by Lehnhardt (1965) and Dieroff (1963) are highly recommended.

3. Is NIPTS a progressive process in the sense that, once started, it continues even though the individual is removed from the noise? Although many people still suspect that this may be so, the evidence is always equivocal (e.g., Hahlbrock and Weyand, 1961; Herrmann, 1962; Baldus and Guttick, 1967). When the hearing of a group of people who have been removed from noise is followed over a period of years, there are always a few who show slight additional losses. However, whether or not the amount of increase is greater than what would be expected in any group of individuals (i.e., whether or not the additional loss is merely sociocusis that occurs because the total acoustic environment of the ears during the intervening years cannot be controlled) is generally disregarded; in my opinion there is as yet no convincing proof that any progressive degenerative process is set in motion.

4. But is the noise-damaged ear more susceptible to further injury than a normal ear? The difficulty in answering this question arises from the difficulty of equating injury to normal and to already-damaged ears. Is a 10-dB increase in PTS in an ear that already had a 40-dB loss smaller, equal, or greater than a 20-dB change in an ear that was initially "normal?" Numerically, it is smaller. But it represents a greater loss of loudness in a normal ear. So again there seems to be no evidence that an ear with some NIPTS is more susceptible than a normal ear, particularly if all temporary effects have completely disappeared.

5. If permanent injury does not occur, does habitual exposure to a moderate noise render the ear more resistant to an occasional high-intensity exposure? That is, does the ear get "tougher"? I suppose this particular speculation developed from an analogy with callouses on the skin. However, there is no evidence that the basilar membrane will become more leathery, or that the middle-ear muscles, which presumably help to protect the inner ear, become stronger as time goes on. In fact, Chizuka (1965) recently found just the opposite: his 15-to-18-year-old boys allegedly showed more auditory fatigue after working in noise for several months than they did at the beginning of employment.

6. Can one distinguish a hearing loss caused by gunfire from one caused by other noise? The popular impression is that the latter tends to be more extensive than the former, with a more gradual slope. In regard to average data, there is some basis for this hypothesis, but in the individual case the slope is no sure indicator. Similarly, both noise-induced and gunfire-induced losses are invariably accompanied by recruitment, and occasionally by abnormal tone-decay (Ward, Fleer, and Glorig, 1961). In view of the fact that in either case the important underlying physiological deficit is probably an area of missing hair cells, it is perhaps not surprising that the etiology cannot be determined after the fact.

7. Are there any exacerbative agents—conditions that will increase the PTS produced by a given noise? Experiments on lower organisms indicate that greater injury can result from noise exposure if exposure is concomitant with mycin therapy (Sato, 1957; Darrouzet and Sobrinho, 1963; Voldrich, 1963).

However, there is little to support the notion that a poor pneumatization of the mastoid (Kosa and Lampe, 1967), an unusual bodily position (Boenninghaus, 1959), or low-frequency vibration heighten susceptibility to permanent damage. An existing TTS may increase susceptibility, according to evidence on cochlear microphonics (Lawrence, 1958), but this evidence is most indirect.

8. *How about ameliorative agents?* Unfortunately, there also seems to be little that one can do to inhibit the growth of PTS or to cure it. For a while, there was hope that massive doses of vitamin A might reduce NIPTS (Ruedi, 1954), but subsequent studies failed to confirm an action of vitamin A on either TTS (Ward and Glorig, 1960) or PTS (Dieroff, 1962). Biochemists in other countries, especially Japan, are studying the effect on TTS and PTS of a broad spectrum of agents including $NaHCO_3$ (Iwatsubo, 1961), adenosine di- and triphosphate (Faltinek, 1965), androgens and estrogens (Matsui et al., 1965), nicotinic acid, and vitamin B_1 (Chiba, 1965), but no clear effect has been demonstrated. Rather than admit that there is no effective therapy for an existing NIPTS, some physicians still recommend stellate blocking, novocaine, hydergin, vasodilators, and vitamins (e.g. Niemeyer, 1962), but placebos would probably do as much good.

9. *Are people with middle-ear problems less susceptible to NIPTS than others?* One might think that in otosclerosis, for instance, less sound reaches the inner ear, so less damage is produced. But even this has yet to be shown unequivocally, and other types of middle-ear troubles seem to exert no consistent effect. The only clear case of protection by middle-ear damage is in regard to explosions: when the eardrum was ruptured by the blast, the NIPTS is generally found to be less than when the drum is unaffected (Akoyoshi et al., 1966).

10. *Can the most susceptible individuals be identified before they suffer a hearing loss?* To this I must answer, "No, and not afterwards, either." Our results with chinchillas imply that TTS and PTS are not closely related, so the only solution is monitoring audiometry, which will allow us to detect beginning NIPTS before it gets too severe. Such a procedure, however, singles out not only the most "susceptible," but also the most unlucky (i.e., those who happened to get a particularly severe exposure on a single occasion) or, perhaps, the most reckless in regard to their hearing outside the work situation.

11. *Finally, is it true that we are continually surrounded by ultrasound—sound too high in frequency to be heard—and so as a result we are being deafened and maddened by this sound we cannot even hear, as some fanatics claim?* I trust the answer to this is implicit in the way the question was phrased, but for assurance, read Parrack's (1966) review.

In summary, then, steady noises above 80 dBA are capable of producing some change in auditory threshold, and above 105 dBA they are sure to produce PTS in the normal unprotected ear if exposure continues, eight hours a day, for several years. We cannot reduce NIPTS except by reducing the effective noise exposure, and there is no way to restore it. Furthermore, we cannot identify the noise-susceptible individual. Therefore pre-employment and monitoring audiometry, together with a program of ear protection, is the only solution now known.

Bibliography

Akoyoshi, M., Amemiya, A., Sato, K., Takeda, T., and Shoji, T. On the pathogenesis of acoustic trauma of the cochlea in rabbits and guinea pigs due to explosion. *Int. Audiol.* **5**, 270-271 (1966).

Atherley, G. R. C., Monday morning auditory threshold in weavers. *Brit. J. Indust. Med.*, **21**, 150-153 (1964).

Baldus, S., and Guttich, H. Langzeitbeobachtungen am Hörvermögen von 4 jungen Männern nach einem Gruppentrauma durch Explosionseinwirking. *HNO* (Berlin), **15**, 201-204 (1967).

Baughn, W. L., Noise control—percent of population protected. *Int. Audiol.*, **5**, 331-338 (1966).

Boenninghaus, H. G., Ungewöhnliche Form einer Hörstörung nach Lärmeinwirkung und Fehlbelastung der Halswirbelsäule. *Z. Laryng. Rhinol.*, **38**, 585-592 (1959).

Botsford, J., Prevalence of impaired hearing groups exposed to various sound levels at work. *J. Acoust. Soc. Amer.* (in press).

Chiba, E., Preventative and therapeutic effects of drugs upon noise injury as seen from the viewpoint of histopathological findings. (Japanese) *Nihon Univ. J. Med.*, **24**, 469-480 (1965).

Chizuka, K., Simplification and practical purposes of auditory adaptation- and fatigue-test, and especially on the change of auditory fatigue of technical students in the noise-environment in progress of time. *Otol. Fukuoka*, **11**, 86-97 (1965).

Darrouzet, J., and Sobrinho, E. D. L., Inner ear, kanamycin and acoustic trauma. Experimental study. *Rev. Brasil Cir.*, **46**, 120-134 (1963).

Dieroff, H. G., Der Einfluss des Vitamins A auf die Lärmschwerhörigkeit. *HNO* (Berlin), **10**, 323-325 (1962).

Dieroff, H. G., *Die Lärmschwerhörigkeit in der Industrie.* Leipzig: Johann Ambrosius Barth (1963).

Faltinek, L., Treatment with adenoside-triphosphoric acid of patients suffering from a suddenly developing perceptive hearing disorder. (Russian) *Vestn. Oto-Rino-Laring.*, **3**, 60-62 (1965).

Glorig, A., and Nixon, J., Hearing losses as a function of age. *Laryngoscope*, **72**, 1596-1610 (1962).

Hahlbrock, K.-H., and Weyand, F., Progredienz traumatischer Innerohrstörungen. *Arch. Ohr.-Nas.-Kehlkpf.*, **178**, 166-175 (1961).

Herrmann, R., Zur Progredienz der Innenohrschwerhörigkeit nach Schädeltraumata. *HNO* (Berlin), **10**, 232-234 (1962).

Itwatsubo, Y., Clinical observation of auditory fatigue. *J. Oto-Rhino-Laryng. Soc. Jap.*, **64**, 1708-1722 (1961).

Kryter, K. D., Ward, W. D., Miller, J. D., and Eldredge, D. H., Hazardous exposure to intermittent and steady-state noise. *J. Acoust. Soc. Am.*, **39**, 451-464 (1966).

Kosa, D., and Lampe, I., Über die Pneumatisation des Warzenfortsatzes bei Lärmarbeitern. *HNO* (Berlin), **15**, 324-325 (1967).

Lawrence, M., Functional changes in inner ear deafness. *Ann. Otol. Rhinol. Laryngl.*, **67**, 802-823 (1958).

Lehnhardt, E., Die Berufsschäden des Ohres. *Arch. Ohr.-Nas.-Kehlkph.*, **185**, 11-242 (1965).

Lehnhardt, E., Die c^5-Senke; ihre Deutung auf Grund allgemeingültiger physiologischer Vorstellungen. *HNO* (Berlin), **14**, 45-52 (1966).

Lehnhardt, E., The C^5-dip: Its interpretation in the light of generally known physiological concepts. *Int. Audiol.*, **6**, 86-95 (1967).

Matsui, K., Sakamoto, H., and Kojama, T., *Studies on the Noise-Induced Temporary Threshold Shift (NITTS) at* C^4*DIP.* Japanese Dept. of Hygiene Pub. (April, 1965), pp. 415-420.

Neimeyer, W., Akutes Lärmtrauma. *HNO* (Berlin), **10**, 320-323 (1962).

Parrack, H. O., Effect of airborne ultrasound on humans. *Int. Audiol.*, **5**, 294-308 (1966).

Peyser, A., Gesundheitswesen u. Krankenfürsorge. Theoretische und experimentelle Grundlagen des persönlichen Schallschutzes. *Deutsche med. Wochenschrift*, **56**, 150-151 (1930).

PEYSER, A., Über Berufskrankheiten des Gehörorgans im Sozialhygiene und im Sozialversicherung. *Schriften d. III. internat. Kong. f. Gewerbekrankh., 1914.* Wien: Holder (1918).

RUEDI, L., Wirkungen des Vitamin A im menschlichen und in tierischen Gehörorgan. *Schweiz. med. Wschr.*, **84**, 1411-1414 (1954).

SATALOFF, J., VASSALO, L., and MENDUKE, H., Temporary and permanent hearing losses. A ten-year follow-up. *Arch. env. Health*, **10**, 67-70 (1965).

SATO, T., A study on experimental acoustic trauma in animals treated with specific poisons for auditory organ. *J. Oto-Rhino-Laryng. Soc. Japan*, **60**, Abstr. 31-32 (1957).

VOLDRICH, L., Dependence of ototoxicity of neomycin on loading of the acoustic analyzer with subtraumatic noise. *CS. Otolaryng.*, **12**, 205-207 (1963).

WARD, W. D., Auditory fatigue and masking. In *Modern Developments in Audiology*. New York: Academic (1963).

WARD, W. D., FLEER, R. E., and GLORIG, A., Characteristics of hearing losses produced by gunfire and by steady noise. *J. aud. Res.*, **1**, 325-356 (1961).

WARD, W. D., and GLORIG, A., The relation between vitamin A and temporary threshold shift. *Acta Oto-laryng.*, **52**, 72-78 (1960).

WARD, W. D., and NELSON, D., TTS and PTS in chinchillas. *J. Acoust. Soc. Amer.* (in press).

Effects of Noise on Speech Intelligibility

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If there is one thing sure about the effects of noise on speech, it is that it is not a new problem. Deafening effects of noise probably started with the discovery of gunpowder, or at least with the industrial revolution, and are only now starting to get out of hand with the invention of the electric guitar. But Demosthenes back in ancient Greece was well aware of how his speech was affected by the noise of waves on the seashore. To get his speech intelligibility score down to around 50%, so as to have an efficient test, he filled his mouth full of pebbles.

Demosthenes was probably not the first to discover one of the cardinal rules of making oneself heard in noise, namely, to speak louder. I say he wasn't first because wives, or at least mates, were in vogue even in the time of Adam. To outtalk Eve, Adam probably discovered shouting. However, until Alexander Graham Bell invented the telephone, the problems of speech and hearing were either in the realm of basic science or were the problems for doctors dealing with speech and hearing defects. With the telephone, however, came problems of intelligibility and intelligibility testing. Lord Rayleigh (1908) found that ". . . if the sounds were given as *ssive* and *ffix*, they were heard normally as five and six." G. A. Campbell (1910) first devised a test of ". . . 20 syllables, each ending in long *i* and preceded by one of the simple consonant sounds. . . ." I. B. Crandall (1917) expanded on Campbell's tests in order to find

> . . . the per cent of consonant sounds accurately transferred . . . [so that he could determine] . . . the importance to articulation of any frequency.

Speech communication in noise started becoming a problem when Henry Ford and the Wright brothers invented our most insidious sources of noise, and DeForest invented the means to give speech a fighting chance against noise.

With telephones, electronic communications, and ever-present noises the time was ripe for Harvey Fletcher at the Bell Telephone Laboratories to really dig into the problems and publish in 1929 the first monumental work in the field with his *Speech and Hearing*.

When whole or parts of communications systems were placed in airplanes and tanks, the real problems of speech in noise became acute. During World War II, L. L. Beranek and coworkers at the Cruft Laboratory at Harvard and

S. S. Stevens and coworkers at the Psycho-Acoustic Laboratories sought solutions to the problems of communicating by speech in noise at a wartime pace.

Stevens was well prepared for this war work, having just published, along with Davis, a landmark book, *Hearing, its Psychology and Physiology* (1938). As a result of the war work Beranek (1949) published *Acoustic Measurements,* the first detailed description of measurement methods for both physicists and psychologists.

To further discuss the effects of noise on speech intelligibility, we will need to define some terms. Most people have some notion of what noise is. For our purposes it is an erratic, intermittent, or statistically random oscillation; unwanted sound—in particular, an unwanted disturbance within a useful frequency band, the band being the one that carries the intelligibility of speech. The intelligibility of speech in turn is, in operational terms, the percentage of spoken syllables, words, phrases, or sentences heard correctly by a group of listeners.

The final criterion for evaluating the intelligibility of speech in noise is indeed objective scores on tests of human subjects listening to test words in noise. We should, therefore, give a short history of and point up some of the advantages and limitations of intelligibility testing.

I have already mentioned Lord Rayleigh's concern and Campbell's and Crandall's early consonant-vowel articulation tests. Between 1919 and 1925 many "articulation tests" were conducted at the Bell Telephone Labs using these nonsense syllables, that is, combinations of English sounds other than words.

Many of the tests we use today originated during World War II at the Psycho-Acoustics Lab. The best known are the phonetically-balanced (PB) words, developed by Egan (1948) and his colleagues. These are lists of 50 monosyllabic words that phonetically represent the English language. Hirsh et al. (1952) have subsequently chosen and recorded 200 of the most common of these words for use in hearing clinics.

There are many other tests. Haagen (1946) and Black (1957) have developed multiple-choice word tests. For example, the listener might have to select from one of these four alternatives: *shook, shout, shut* and *shot;* or among *flip, limp blimp,* and *limb.* The advantage of these is that the subject's response is limited to one of four choices versus one of a thousand for Egan's PB words or one of two hundred for Hirsh's PB words.

There are many types of sentence tests, such as the single-word answer types (Hudgins et al., 1947). In these, the listener's ability to hear is deduced from his answer to, for example, "What letter comes after *c*?" There are also the 5-key-word types of sentences, such as, "This *soup tastes like stewed buzzard.*"

Recently Speaks (1967) has proposed using "synthetics sentences" that are third order appoximations to the English language. He finds that these sentences (Women View Men With Green Paper Should) are the best materials for rating hearing aids.

More recent innovations have been Fairbanks (1958) rhyme words and the House et al. (1965) modified rhyme words. Here the listener chooses from, for example, *look*, *cook*, *hook*, *shook*, *took*, and *book*. The advantages of the modified rhyme tests are that the number of alternate responses is small and fixed, and it is easy to see what consonants are most often confused with what other consonants.

With these varieties of tests it is necessary to have conversion charts to transform word or syllable scores to predicted sentence scores and vice versa. The question which usually needs to be asked is what word score will allow an adequate sentence or everyday speech score.

Why so many tests? Which one should be used? Williams and Hecker (1967) suggest that four requirements be assessed in choosing which test should be used for evaluating different communication systems or, in our case, evaluating the effects of various noises. If the requirement is to discriminate among highly intelligible systems, use a difficult test like 1000 PB words. If you want to find out how everyday speech will be heard, use sentences. If you want to know what speech phonemes are apt to be lost, use modified rhyme words or nonsense syllables. If testing time is limited, use multiple choice words or Fairbanks rhyme words.

After determining how to measure speech intelligibility, the next step is to see what makes speech intelligible and later how noise destroys this intelligibility.

To be intelligible, speech must of course be heard, and within reason, the louder the speech is spoken or amplified in communications systems, the more intelligible the speech. The second factor in making speech intelligible is the bandwidth that is passed for the ear to listen to.

Figure 1 shows the relationship between voice level and voice spectrum, i.e., the amount of voice energy in specified octave bands as a function of voice level. The particular data in Figure 1 are from a Western Electro-Acoustics Laboratory report (1959), although similar curves have been published by Dunn and White (1940), who showed what percentage of the time voice peaks exceed a given value; Rudmose et al. (1948), who showed the variability among seven male talkers; Benson and Hirsh (1953), who showed both a male and a female voice spectrum; and Webster and Klumpp (1962), who showed the level and spectral changes due to the automatic raising of voice level to overcome surrounding noises. As Figure 1 shows, frequencies between about 100 and 7000 Hz are present in speech, and levels can change over a 50-60 dB range.

In general, the greater the voice intensity and the broader the voice spectrum, the greater the intelligibility. However, many people have shown that intelligibility decreases once the voice level exceeds a "very loud" level. Figure 2 shows the results of Pickett (1956); similar results have been shown by Fletcher and Steinberg (1929), French and Steinberg (1947), and Beranek (1947a).

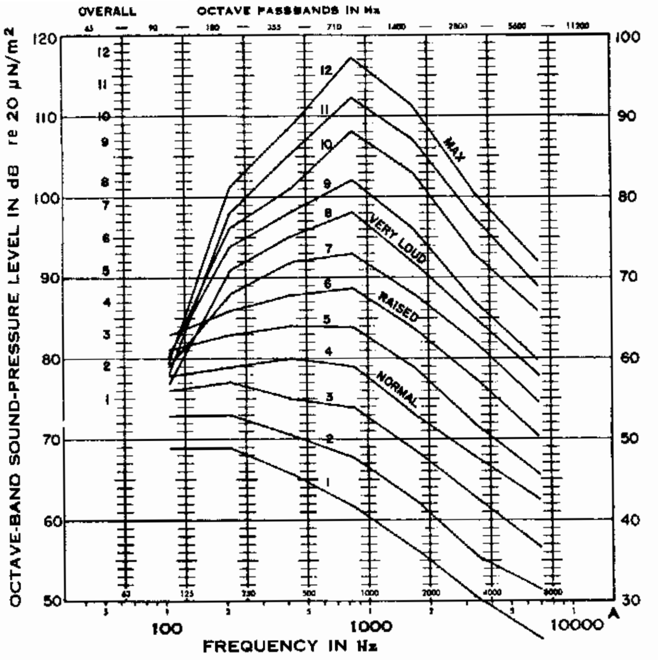

FIGURE 1. Long time average speech spectrum 1 in (left or 1 ft right), from the lips for "Joe took father's shoebench out, she was waiting on my lawn." For levels at the lips add 8 dB to the 1 in levels. For levels at 1 m subtract 10 dB from the 1 ft levels. To convert from octave-band levels to spectrum-band levels subtract 20 dB at 125 Hz, 23 at 250, 26 at 500, 29 at 1000, 32 at 2000, and 35 dB at 4000 Hz (Western Electro-Acoustics Lab., 1959).

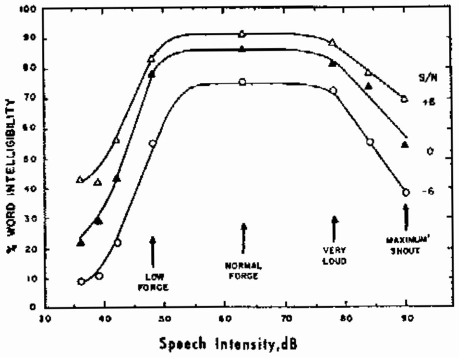

FIGURE 2. Relations between speech intelligibility in noise and vocal force measured as speech intensity 1 m from lips in a free field. Parameter, overall signal-to-noise ratio, in dB. Noise, 70 dB, flat spectrum (Pickett, 1956).

In general, there is a tradeoff between speech intensity and bandwidth for equal intelligibility. This is probably shown best by the data of Egan and Wiener (1946) in Figure 3. This shows, for example, that to retain an intelligibility score of 30% after reducing the bandwidth from 700-3200 Hz to 1100-2000 Hz, one must increase the relative gain from 10 to 30 dB. Note that there is about a 30-dB limit in levels that are acceptable and that the important frequencies are symmetrical around about 1500 Hz.

For more details on the relations between bandwidth and center frequency, look for a moment at Table 1, from Webster (1964a) but based on the Egan and Wiener data. The most intelligible conditions are listed at the top of the table, rank ordered to the least intelligible at the bottom. At the extreme right is the bandwidth that correlates with intelligibility, measured in octaves, not

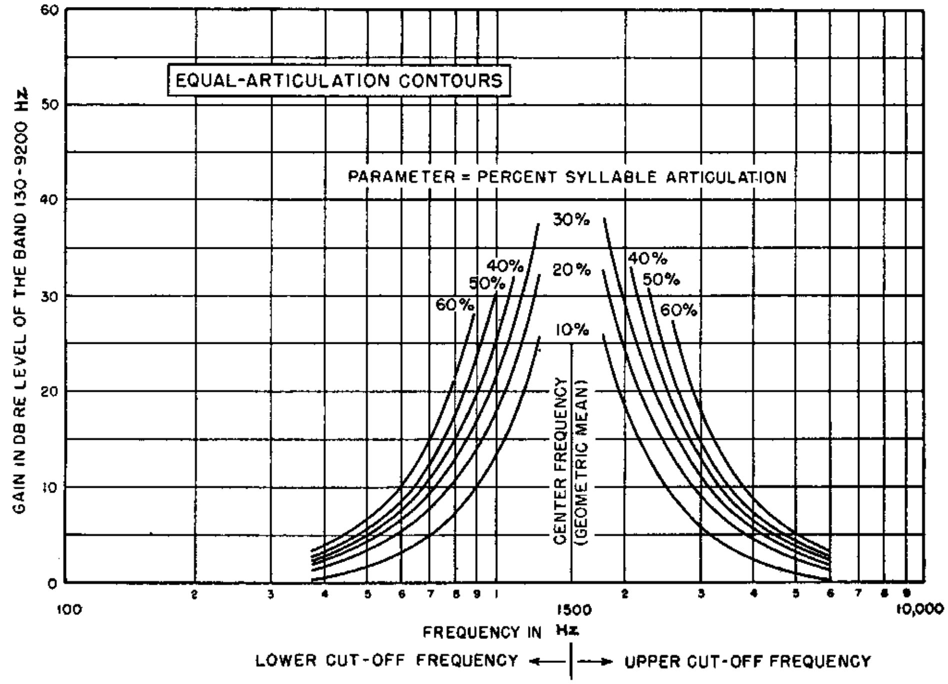

Figure 3. These equal-articulation contours are plotted for band-pass systems all having a center frequency of 1500 Hz. The same contours may be used to predict relative performance of pass bands having other center frequencies, provided the family of contours is shifted horizontally to make them correspond to the new center frequency. The contours are based on data obtained with both Spectra A and B, unfiltered (Egan and Wiener, 1946).

Table 1. Intelligibility versus bandwidth (from Egan and Wiener, 1946).

Word Intelligibility					*Bandwidth*	
% at High S-N Values	*% at Low S-N Values*	*Rel. Rank*	*Band Extent in Hz*	*Band Center in Hz*	*in Hz*	*in Octaves*
88	63	1	130–9200	1093	9070	6.14
81	46	2a	550–6500	1920	5950	3.56
79	50	2b	340–3900	1150	3560	3.52
77	42	3	550–3900	1460	3350	2.82
70	30	4	550–2500	1170	1950	2.18
65	25	5	870–3900	1840	3030	2.16
53	18	6a	870–2500	1480	1630	1.52
44	22	6b	550–1500	908	950	1.46
42	12	7	1300–3100	2007	1800	1.25
22	10	8	870–1500	1120	630	0.79
20	5	9a	1300–1900	1580	600	0.55
18	6	9b	1800–2500	2120	700	0.47

cycles. Note, for example, that the second and third most intelligible systems, which are equally intelligible and have equal bandwidths in octaves, differ by a factor of 1.67 in bandwidth in cycles. There are other examples which show that within the general confines of the frequencies from 1000 to 2000 Hz, equal intelligibility can be had with smaller bandwidth in cycles if the center frequency is closer to 1000 than to 2000 Hz. For example, relative ranks 4 and 5 have the same bandwidth in octaves but differ by a factor of about 1.6 in bandwidth; the one with the lowest center frequency and smallest bandwidth is the more intelligible.

Instead of band-passing the middle frequencies in the speech spectra, many studies have determined intelligibility as a function of increasingly severe high or low-pass filtering (see Steinberg, 1929; Egan and Wiener, 1946; French and Steinberg, 1947; Pollack, 1948; and Dyer, 1962). Typical results (French and Steinberg) are shown in Figure 4. Note that the broader the bandwidth and the greater the level (except the highest levels), the greater the intelligibility.

Figure 5 (again from French and Steinberg) shows the same basic data in different form, namely, intelligibility in terms of a "derived additive A scale" as a function of low-pass cutoff frequency for three different voice levels. This derived A scale, called the AI or Articulation Index, was originally developed by French and Steinberg (1947). According to Kryter (1950), Collard (1930) and Zoldakov (1940) had shown that the procedures used to arrive at the additive scale would be valid.

Dudley (1968) pointed out that Fletcher (1922) and Fletcher and Steinberg (1929) were already exploring some of the basic concepts in the AI formulation in the twenties.

To complete the Articulation Index or AI story as simply as possible, refer to

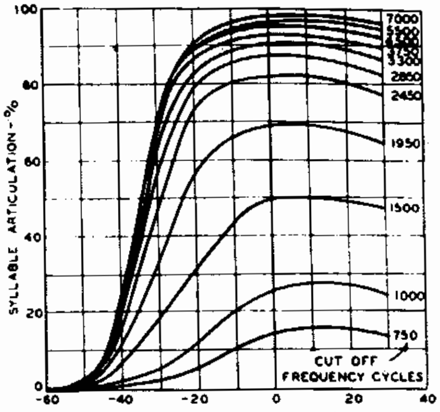

FIGURE 4. Smoothed results of 1928-1929 articulation tests on low pass filters having the indicated cutoff frequencies (French and Steinberg, 1947).

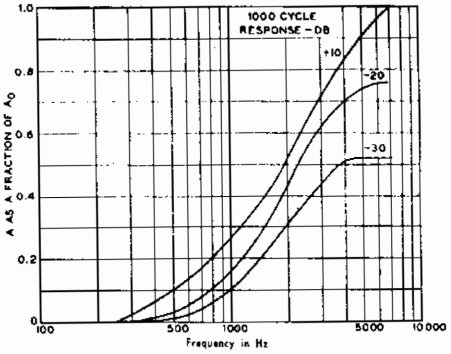

FIGURE 5. Relation between articulation index and cutoff frequency at three different settings of the test circuit. Articulation index is expressed as a fraction of the articulation index (A_o) of test circuit at its optimum setting (French and Steinberg, 1947).

Figure 5 and note that half of the AI (A = 0.5) lies in frequencies below 2000 (actually 1900) Hz. And by the additive principle, the remaining half lies in frequencies above 1900 Hz. This is at the upper end of the midfrequencies shown to be important by Egan and Wiener in Figure 3 and Table 1.

The center frequency of frequency bands that contribute equally to the AI can be read directly off Figure 5. If 20 bands are wanted, and that is what French and Steinberg chose, you merely read the frequency on the abscissa corresponding to points on the AI scale of 0.05, 0.1, 0.15–to 1.00. Lest anyone get carried away with how simple this procedure is, let me warn that getting from percent syllables correct or percent words correct to the additive. AI scale is neither conceptually nor operationally all that simple. Once the conversion is made, however, 20 bands can be read off as shown in the third column of Table 2 taken from Black (1959). The first and second columns of Table 2 show the 20 bands when multiple choice or PB words were used instead of nonsense syllables in the original filtered tests.

To use the AI for predicting speech intelligibility in noise, physical measurements of the speech level and the noise level are required. Kryter (1962a) has prepared worksheets to calculate the AI from measures of speech and noise in 20 bands (Figure 6). Beranek (1947a) was the first to point out that speech levels above 95 dB (spectrum level) did not contribute to intelligibility, and in Kryter's (1962a) worksheets account is taken of this maximum level of allowable speech, even when speech peak clipping is used. The speech

TABLE 2. Twenty frequency bands contributing equally to the Articulation Index (from Black, 1959).

	Multiple Choice	*Write-Down Monosyllables*	*French and Steinberg*
1	150–230	300–400	250–375
2	230–400	400–500	375–505
3	400–565	500–600	505–645
4	565–700	600–690	645–795
5	700–850	690–760	795–955
6	850–1000	760–850	955–1130
7	1000–1150	850–950	1130–1315
8	1150–1350	950–1100	1315–1515
9	1350–1500	1100–1250	1515–1720
10	1500–1700	1250–1450	1720–1930
11	1700–1950	1450–1750	1930–2140
12	1950–2200	1750–1975	2140–2355
13	2200–2550	1975–2200	2355–2600
14	2550–2800	2200–2350	2600–2900
15	2800–3000	2350–2550	2900–3255
16	3000–3400	2550–2700	3255–3680
17	3400–3800	2700–2950	3680–4200
18	3800–4700	2950–3450	4200–4860
19	4700–5500	3450–5000	4860–5720
20	5500–7000	5000–7000	5720–7000

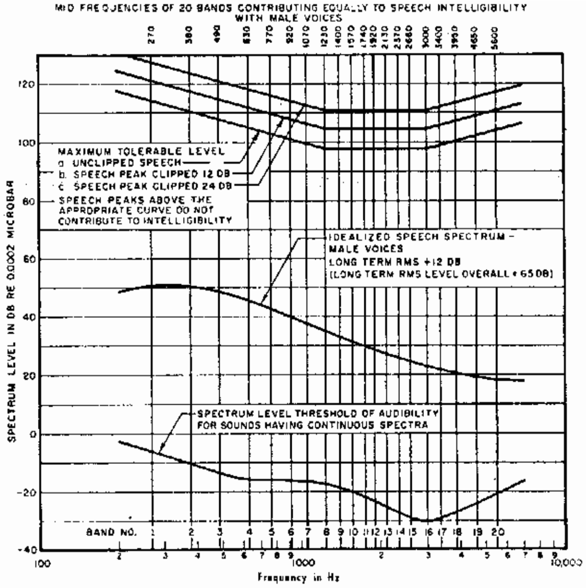

Figure 6. Worksheet for AI—20-band method (Kryter, 1962a).

spectrum is already drawn in at conversational level. The greatest concentration of "equally contributing bands" are centered just below 2000 Hz.

For most people, measuring the narrow and nonuniform bands specified is difficult, if not impossible, so a more usual worksheet is shown in Figure 7, where measurements are made in octave bands. Worksheets are also available for ⅓ and ½ octave bands.

The steps involved in using these worksheets is as follows: Plot the measured noise spectrum. Adjust the speech spectrum to reflect its actual level. Measure the positive differences between speech and noise in each band that lie between zero and 30 dB. Multiply the value in each band by a constant (which accounts for differences in importance among the several bands) and add the resultant numbers (to arrive at some value between zero and one).

How well does the Articulation Index, which was formulated on the basis of filtering speech, predict speech heard in noise?

Let us consider two of the many studies which show the dependence of speech intelligibility in noise on the relative spectra of speech and noise. Miller (1947) found that as compared to the masking done by the broad-band noise, (1) low-frequency noise bands did virtually no masking at low levels and were very good maskers at high levels, (2) high-frequency bands of noise were very effective maskers at low levels but did not mask at the same rate as the levels increased, and (3) at moderate to high levels, bands below 1500 Hz and especially those below 1100 Hz masked speech considerably better than those above 1300 Hz. His results can be summarized by saying that as the level of noise increases, the masking effectiveness changes from higher frequency

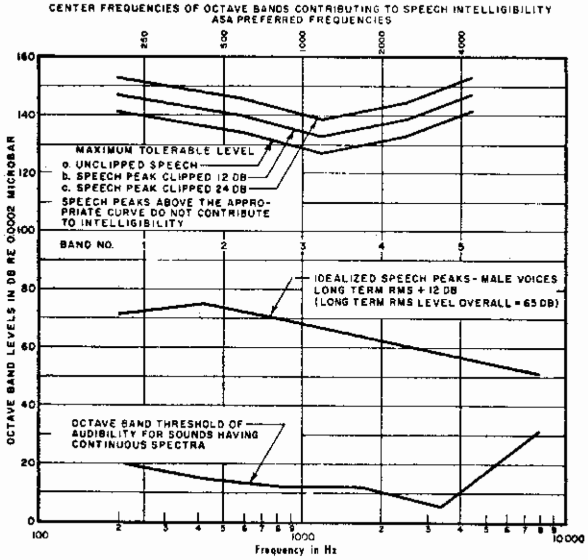

FIGURE 7. Worksheet for AI—octave-band method, ASA-preferred frequencies (Kryter, 1962a).

bands to lower frequency bands. Pickett and Kryter (1955), using sloped broad-band noises to mask speech, found, like Miller, that "low-frequency noise" was not very effective in decreasing high levels of intelligibility but quite effective in further decreasing low levels. Again like Miller, they found that high-frequency noise was quite effective in decreasing high levels of intelligibility but relatively less effective at decreasing lower levels.

Kryter (1962b) has shown (Figure 8) that the AI handles Miller's data fairly well, with one obvious exception. In general, the AI does predict intelligibility well for steady-state, broad-band noises.

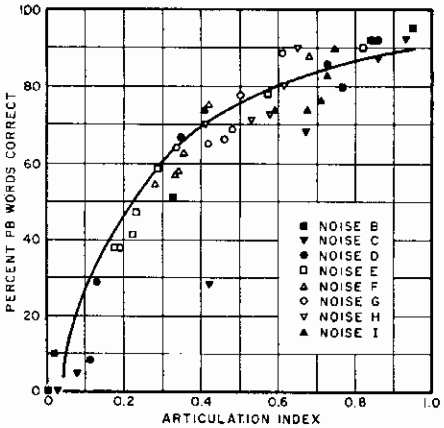

FIGURE 8. Comparison of obtained and predicted test scores for broad-band speech in the presence of narrow bands of noise set at various intensity levels (after Miller, 1947) (Kryter, 1962b).

Licklider (1959), in a critical evaluation of the AI as an auditory theory for perceiving speech, points out many of its flaws. The primary one is that not just the area but the shape of the area between the speech and noise spectra is related to intelligibility. In particular, thin flat areas (wide bandwidth low speech-to-noise differential) give higher intelligibility scores than equal areas that are tall and narrow (narrow bandwidth high speech-to-noise differential). Beranek (1947a) in commenting on this same observation said

> the reason . . . must be that the ear is more able psychologically to piece together fragmentary information from many bands into the complete syllable than it is if more information is given in fewer bands.

Licklider concludes, however, by saying the AI

> . . . constitutes a fair engineering approximation . . . [but] . . . not . . . a fair model . . . to understand the process of hearing.

Although the AI is probably the most accurate way of predicting the effects of noise on speech intelligibility, it is difficult for relatively naive technicians to use and more difficult for laymen to interpret. Almost immediately after introduction of the AI in 1947 L. L. Beranek (1947a) proposed a simplified substitute for it which he dubbed the "speech interference level" of noise, or the SIL. Beranek's SIL is the simple average of the octave-band levels (in decibels) in the three octave bands lying between 600 and 4800 Hz. Although Beranek (1954) tells how to measure speech and combine it with SIL to get an equivalent AI, the SIL itself measures only the noise, and reference must be made to a table (Table 3) that tells what voice level is needed to communicate at given distances between talker and listener.

In validating Beranek's SIL, Rosenblith and Stevens (1953) show that when SILs are computed from Miller's (1947) data they agree "within a few decibels" with the appropriate values shown in Table 3. However, Miller's data, which we've discussed before, shows that noise bands below 600 Hz at high levels are very effective in masking speech. Similarly Stevens, Miller, and Truscott (1946) show that the best pure-tone masker of speech is 500 Hz. So Beranek, as originally published in Beranek, Reynolds, and Wilson (1953) constructed a set of Speech Communication criteria (SC) contours for estima-

TABLE 3. Speech Interference levels (in dB re 0.0002 dyne/cm²) which barely permit reliable conversation at the distances and voice levels indicated (from Beranek, 1947b).

Voice Level *Distance (ft)*	*Normal*	*Raised*	*Very Loud*	*Shouting*
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61

ting SIL which took into account the masking properties of the lower frequencies (Figure 9). Beranek's SC contours are described in more detail by Rosenblith and Stevens (1953) and were subsequently revised by Beranek (1956, 1957) into the more familiar Noise Criteria (NC) and Alternate Noise Criteria (NCA) curves. In general NC, NCA, SC, or for that matter Noise Rating (NR) curves proposed by the International Standard Organization, ISO (1964), are curves that

> specify for each octave band of the masking noise and sound-pressure level that must not be exceeded . . . for a (specific) SIL to be realized. (Rosenblith and Stevens, 1953)

When discussing the SIL, Beranek (1954) suggests averaging in the level in the 300-600 Hz octave for noises where it exceeds by 10 dB the level in the 600-1200 Hz octave. Strasberg (1962) specified that on U. S. Navy ships the 300-600 Hz octave always be used together with the octaves from 600 to 4800

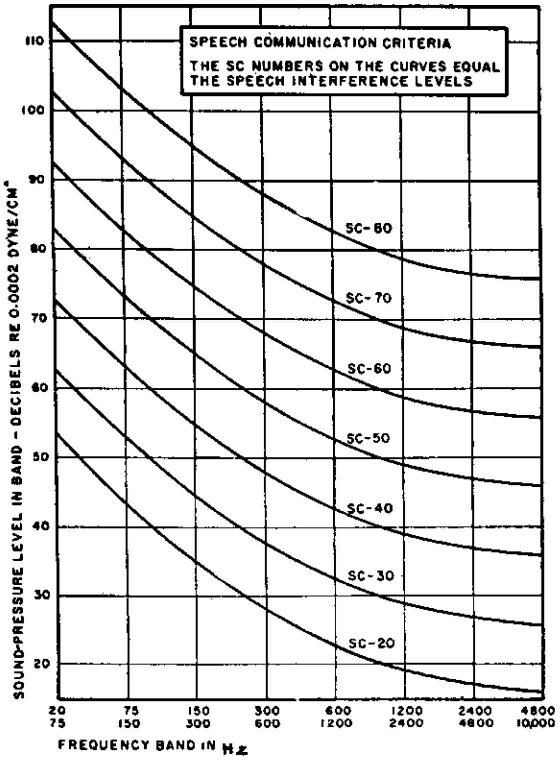

FIGURE 9. Speech communication criteria curves. The SC numbers on the curves equal the speech interference level (Beranek, Reynolds, and Wilson, 1953).

Hz. Pickett and Kryter (1955) suggested using five octaves from 300 to 9600 but doubling the weight of the octaves 1200 to 2400 and 2400 to 4800 Hz.

To summarize briefly, I've mentioned two general methods of rating noises for speech interference: an averaging method utilizing the AI or SIL schemes and a curve-fitting method. Loudness level (phons) or perceived noisiness (PNdB) (Kryter, 1960) can also be calculated, and PNdB has been suggested by Kryter and Williams (1966) as being a good measure of speech interference. However, as Young (1958) said, "Don't forget the simple sound-level meter." He found that noises measured using the A-weighting in a sound level meter give pretty good approximations to "loudness," and in a later paper (1964) he showed the similarity in the shapes of curves used to rate noises and the A-weighting network of the sound level meter (Figure 10). Note also that the average decibel reading at the octaves 500, 1000, and 2000 Hz is well estimated by most of the curves in Figure 10. It is not surprising, therefore, that fairly high correlations exist between many of these measures of noise and some of the various attributes of noise they are purported to measure, namely, office acceptability and the annoyance of airplane noises, both of which have an element of speech communications in them.

How well do these various physical measures of noise measure the speech interfering aspects of noise? Klumpp and Webster (1963) adjusted the levels of 16 noises until 8 listeners individually got 50% of Fairbanks (1958) rhyme words correct. We then measured these equally speech-interfering noises by about every known measurement method. That measure that came closest

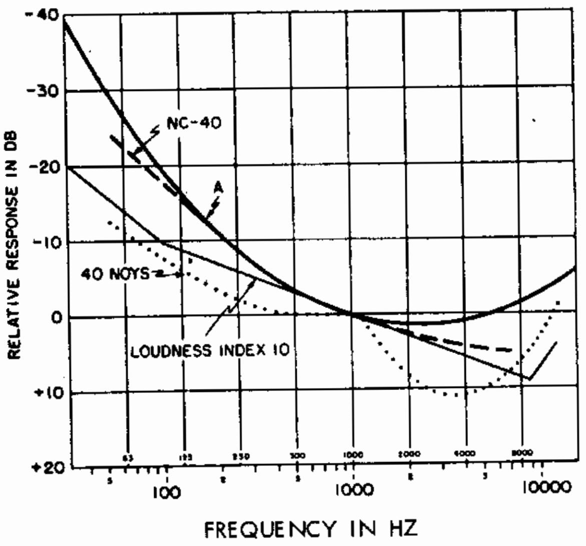

FIGURE 10. Examples of curves used in finding NC level, A-sound level, perceived-noise level, and loudness level (Young, 1964).

to yielding the same value on each of the 16 noises would be the best measure of speech interference, since each noise had been adjusted in level to yield equal word scores. In Figure 11, which lists the 16 noises along the abscissa and the numerical measure in dB of the various methods on the ordinate, a straight horizontal line would be the ideal measure. The noises are listed from left to right such that noises with a preponderance of energy in the lower frequency regions are to the left (note the position of TN-6—thermal noise whose spectrum level has a minus 6 dB per octave slope), flat noises are slightly right of center (note TN—thermal noise), and high-frequency noises are at the right (note TN + 6).

The C level (flat from 100 to 10,000 Hz) is probably the worst measure that could be used. An overall sound level meter measure of noise tells next to nothing about the speech-interfering property of the noise: the values vary from 79 dB to 105 dB, a range of 26 dB for equally speech-interfering noises. The A-weighting values are much better, but all sound level meter measures overrate the speech-interfering properties of high-frequency-type noises.

The speech interference level or SIL measures do considerably better as a group. The particular octaves chosen for the SIL average make a considerable difference. The conventional Beranek octaves of 600 to 4800 Hz underestimate the low-frequency noises and overestimate the high-frequency noises. Averaging in the 300 to 600 Hz octave, on all noises, as Beranek (1954) suggests,

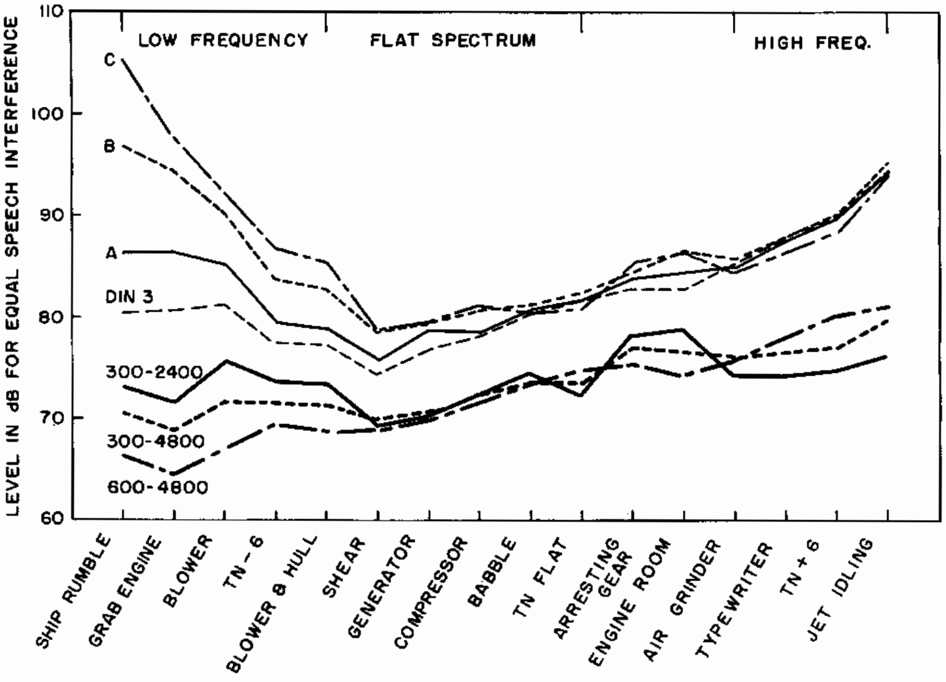

FIGURE 11. Measured or calculated levels in dB for 16 noises equated in level to be equally speech-interfering (Klumpp and Webster, 1963).

"... if the levels in the 300-to-600 cps band are more than 10 dB above those in the 600-to-1200 cps band . . ." gives a better estimate. But the best SIL measure is the one that averages the four octaves 300 to 2400 Hz, closely followed by averages of the three octaves centered at 500, 1000, and 2000 Hz (not shown in Figure 11).

Table 4 provides a statistical estimate of how these and a few other measures compare. The measurement method that yields the lowest standard deviation, a measure of dispersion or variability, on the 16 noise measurement scores is the best speech interference measure. As a group, the frequency-weighting values vary from 4.7 for the A-weighting to 7.4 for the C. Tangent-to-curve measures range from 4.8 to 6.8, SIL measures vary from 2.5 to 4.8.

Kryter and Williams (1966) found no difference among the measures marked with asterisks in predicting speech intelligibility of various aircraft noises. Young (1964) found that the measures marked with the daggers correlate 0.91 or greater with subjective judgments of office noises rated by Beranek (1956) in developing the NC and NCA rating curves. Speech intelligibility is one important criterion in judging the "noisiness" of an office.

Botsford (1967a, 1967b) recently proposed a correction based on the difference between levels measured with C-weighted and A-weighted networks to rate many aspects of noises including speech interfering effects. He draws a monograph to relate A (modified by C-A) to voice level and distance

TABLE 4. Standard deviations of predicted speech-interfering indices for 16 shipboard noises of equal speech-interfering capability, as determined by 14 different rating methods (after Klumpp and Webster, 1963).

Method	*Standard Deviation*
Frequency weighting	
SLM C-scale	7.4
SLM B-scale	5.5
SLM A-scale*†	4.7
Botsford Modified A-scale	4.5
DIN 3 (German standard)	5.0
PNdB*†	5.2
AI (20-bands)	2.4
Tangent-to-curve	
NC	6.8
NCA*†	5.2
ISO	6.4
ISO (Restricted)†	4.8
SIL calculations with octave bands	
600–4800 Hz*	4.8
300–4800 Hz	3.1
300–2400 Hz†	2.5
350–2800 Hz	2.8
175–2800 Hz	2.7

*† For explanation of asterisks and daggers see text.

or to estimate SIL (Figure 12). Unfortunately, the 16 noises of Klumpp and Webster (1963), which are plotted by number on Figure 12, are not rated well by Botsford's nomograph. One major reason for this is that Klumpp and Webster's noises are representative of many diverse types of shipboard (and laboratory) noises and not just the "factory (low-frequency) type," used by Botsford in validating his scheme. Because of the greater diversity of the Klumpp and Webster noises, it is not too surprising that Botsford's nomograph does not predict their speech interference effects much better than A-weighting alone. As compared to the unmodified A-weighting, Botsford's modified A-weighting does reduce the standard deviation from 4.7 to 4.5, but this is not a significant reduction. Similar arguments hold when Kryter and Williams (1966) show that PNdB measures the speech-interfering properties of "aircraft noises" as well as any other measure. The fact is that the PNdB scheme does not rate Klumpp and Webster's (1963) more diverse sampling of noises as well as, say, the three-band preferred octave SIL (500/1000/2000).

For Klumpp and Webster's 16 noises the best sets of speech interfering measures are those SILs that include 500 Hz—i.e., all SIL measures except the original one, which spanned only the range from 600 to 4800 Hz—and the

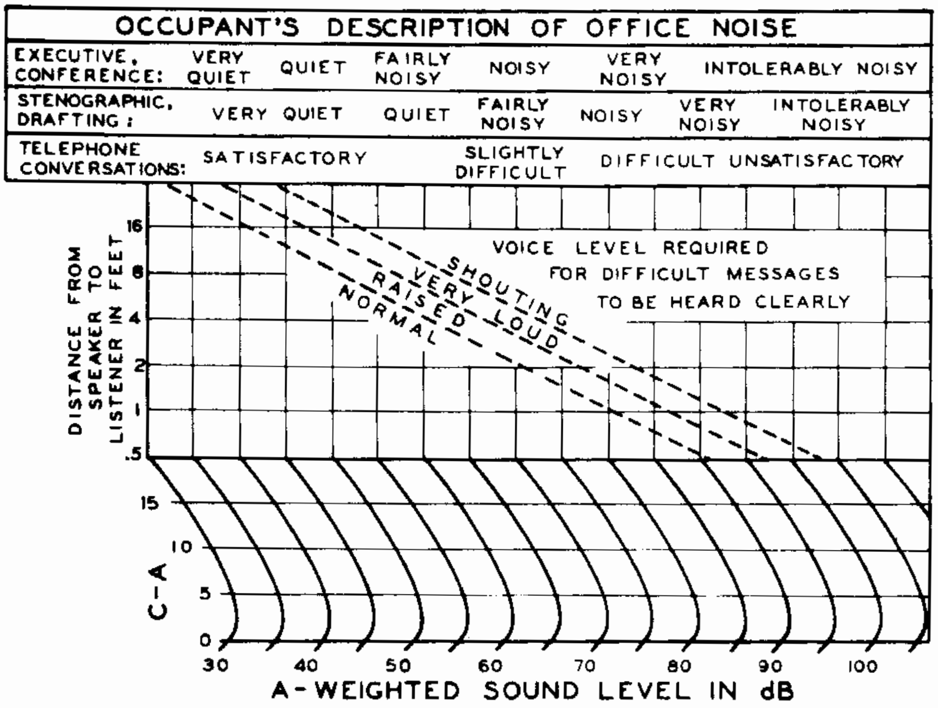

FIGURE 12. Speech interference effects of sound levels. To use the graph, locate, in the curved grid at the bottom, the point corresponding to the sound levels of the noise under consideration and read directly above it the effects predicted (Botsford, 1967b).

20-band AI (which was also marginally better for the Kryter and Williams aircraft noises).

In this report I shall not detail the arguments and counter-arguments about the development of a proposed set of new contours and a sound level weighting network. But I should like to mention the following points, briefly.

Figure 13 shows the range of spectra and levels of Klumpp and Webster's 16 noises when adjusted to be equally speech interfering. A curve of the form shown in Figure 14 would best fit those spectra. The inverse of this curve, that is, a filter network that passes frequencies around 1000 Hz and discriminates quite drastically against frequencies below 125 Hz and above 4000 Hz, is the proposed speech interference (SI) network for a sound-level meter.

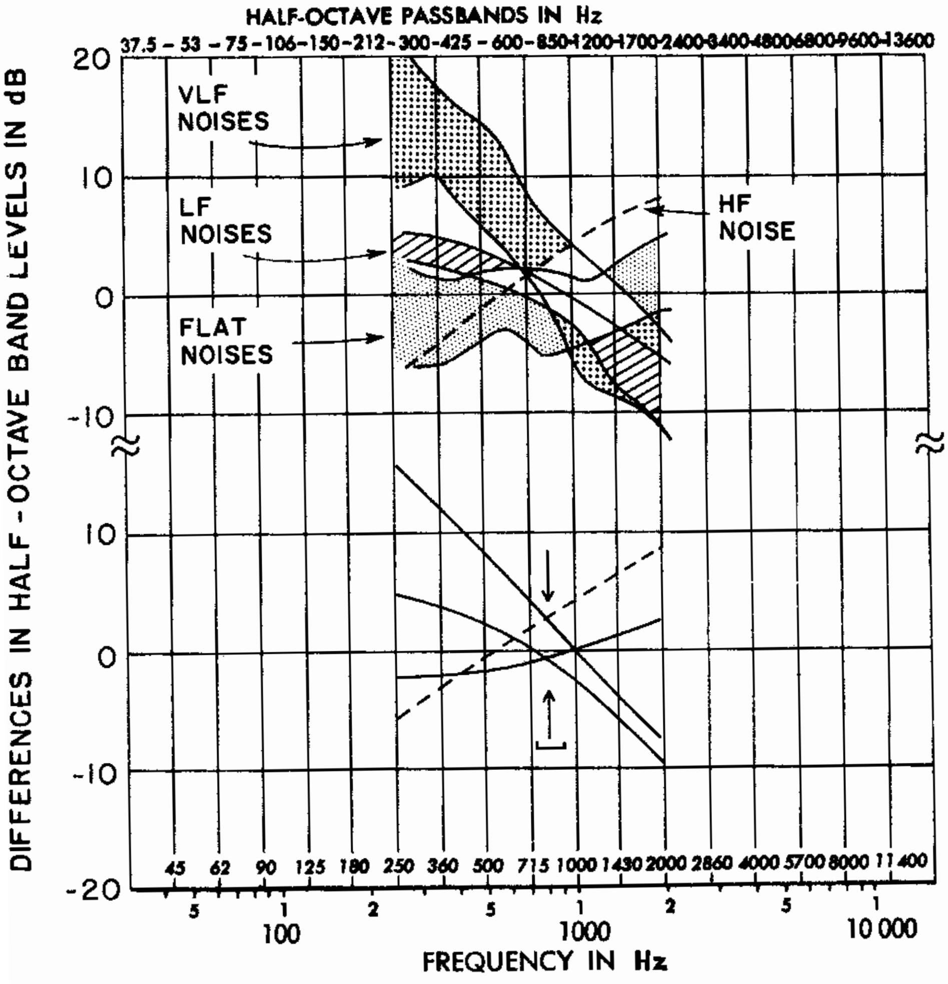

FIGURE 13. Superposition of masked audiograms due to spectra of equally speech interfering noises, showing crossover or importance frequency (Webster, 1964c).

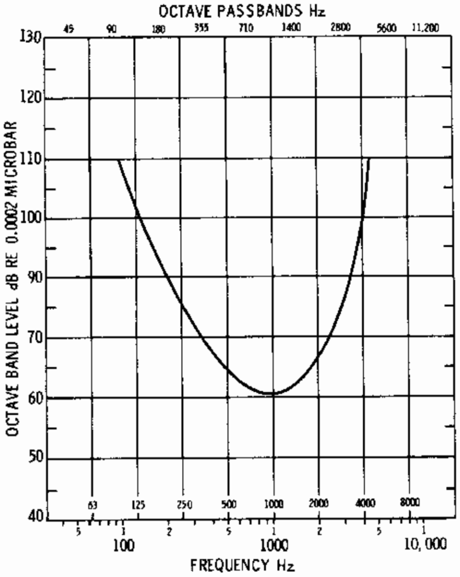

Figure 14. Proposed Speech Interference (SI) frequency weighting network. If used as a filter network in a sound-level meter, the inverse of this curve should be used, i.e., the filter should pass the frequency band center around 100 Hz and discriminate against higher and lower frequency regions, especially those below 300 Hz and above 3000 Hz (Webster, 1965).

The one aspect of the speech-interfering properties of noise that has been implicit for years but never fully recognized is that as the noise level increases, or as the speech task gets more demanding, the lower frequency speech frequencies become relatively more important. Or stated conversely, the adverse effects of low-frequency noise become more pronounced. The best example is from Miller (1947), whose results, discussed earlier in this paper, are presented in Figure 15. Notice how as the noise level (the parameter) increases, the deleterious effect of the lower-frequency noises on word intelligibility increases drastically.

As stated earlier in this paper, Pickett and Kryter (1955) noted the same effect using broadband but sloped noises. Pollack (1948) and Dyer (1962) found that the frequency that divided the speech range into two equally-intelligible parts shifted downward as the noise level increased. The present AI weightings (Figure 16) take this into account. Note that for an assumed conversational level voice, as the noise level increases the band of noise that is most effective in masking speech shifts downward.

Webster (1964a, b) discusses these effects in some detail. It suffices here to say that the contours shown in Figure 17 reflect the changing importance of the speech-interfering properties of the various frequency regions of noise with noise level. As shown, these contours are suggested additions to the top end of Beranek's (1957) NCA contours to rate offices in really noisy environments, as on military ships and probably in machine shops. These top contours reflect only the speech-interfering properties of noise—not annoyance, loudness, or overall acceptability.

To summarize: the ability to communicate by voice in noise is determined by (1) the level and spectrum of the noise (which can be fairly well specified by the SIL based on octaves centered at 500, 1000, and 2000 Hz); (2) the voice level of the talker; (3) the distance between the talker's mouth and the

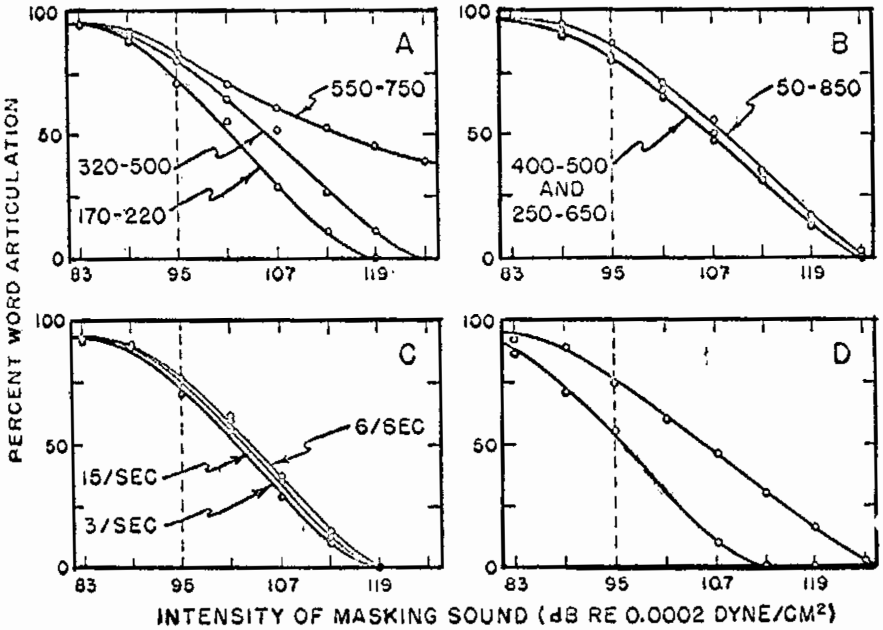

FIGURE 15. Word scores as a function of the component frequencies of the masking noise for different noise levels. The speech level was 95 dB (Miller, 1947).

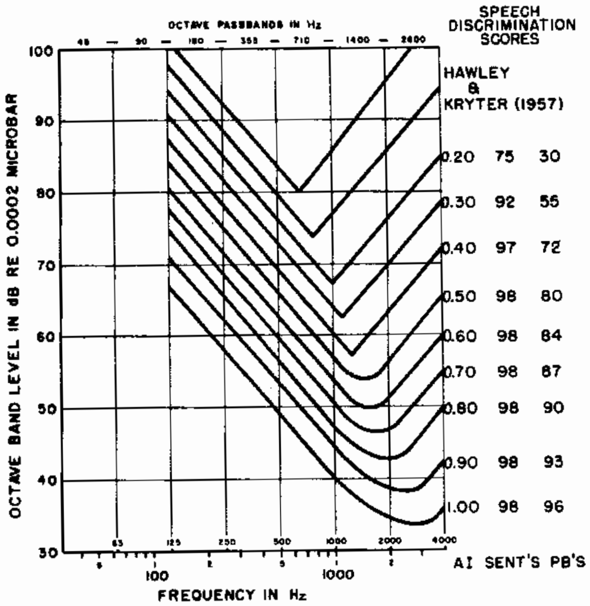

FIGURE 16. Permissible noise levels for indicated Articulation Index (AI) scores when speech is spoken at a "conversational level." AI contours and the corresponding sentence and PB word scores are indicated at the right (Webster, 1964c).

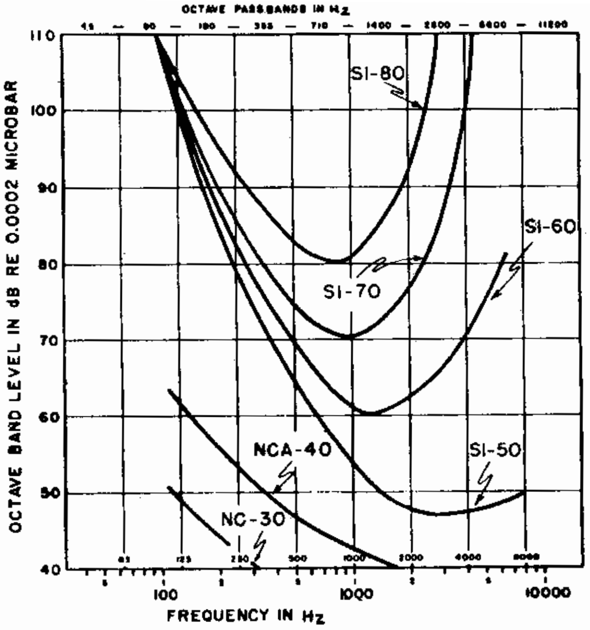

FIGURE 17. Proposed Speech Interference (SI) noise rating curves to be added to, and used as, Beranek's NC and NCA contours. To be used where noise levels exceed ideally accepted office noises but where speech communication is still necessary. Curves to be used to estimate PSIL (Webster, 1964a).

listener's ear (both of which are accounted for in AI and SIL calculations); and (4) the vocabulary used (which requires a conversion graph). Having noted the restrictions and some of the history, limitations, and rationale of the measurement methods, let us now review some summary figures of the limits of communications by voice in noise.

Figure 18 shows the percent of Fairbanks (1958) rhyme words correctly understood in increasing levels of noise under conditions of face-to-face using sound-powered phones and electronic amplification systems. In the face-to-face situation, the noisier it gets, the closer together people must get. The sound-powered phone condition can be considered an extension of face-to-face where the distance is ¼ inch. In both the sound-powered and the amplified speech cases the largest differences depend on lack of, mediocre, or good soundproofing of the equipment. However, the exact type of earphone and microphone selected, and the voice level, can all affect communications effectiveness. (For details on performance of different microphones and earphones, see WEAL, 1959.)

Since most of us are probably primarily interested in the face-to-face aspects of communicating in noise, let us procede by examining a plot similar to the one used by Botsford (1967b). Figure 19 shows a detailed cross-comparison of

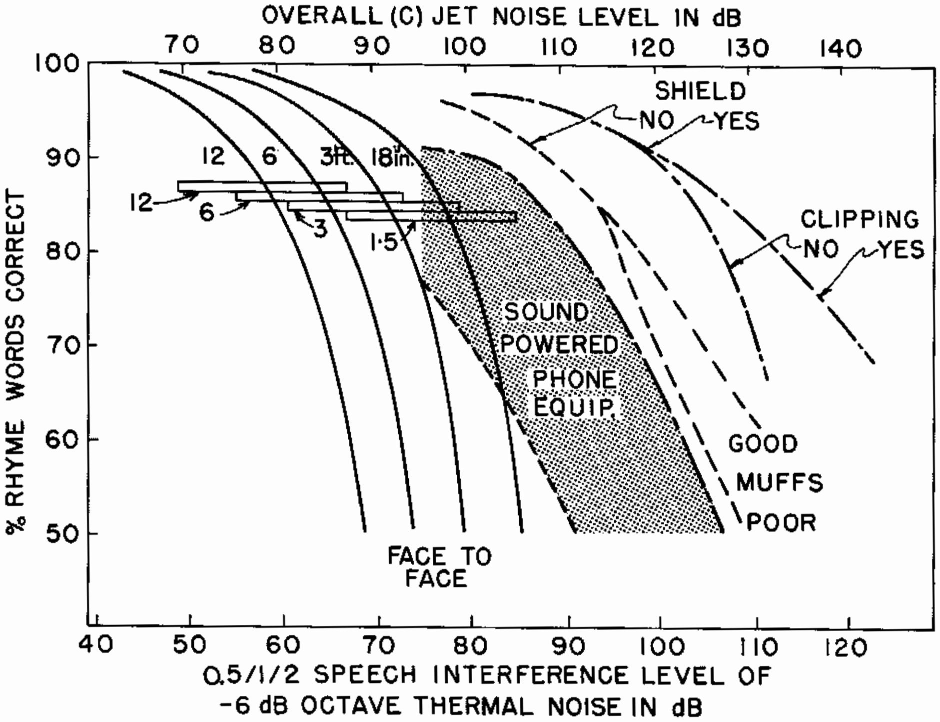

FIGURE 18. Speech intelligibility (percent rhyme words correct) as a function of jet-aircraft idling noise level. On the top abscissa, noise levels are listed as measured on the C-weighting network of a sound-level meter. On the bottom abscissa, the noise level is listed as the speech interference level (SIL), based on the octaves centered at 500, 1000, and 2000 Hz, of a minus 6-dB/oct shaped thermal noise that is equivalent in its ability to interfere with the intelligibility of speech to the jet-noise levels listed on the top abscissa. Three generic types of results are shown: face-to-face, sound-powered phone, and amplified speech. Within the face-to-face results, the parameter is distance between talker and listener. The limits on the sound-powered results are present-day "operational" (to the left) and "developmental" equipment (to the right). In the amplified-speech results, the major parameter is presence or absence of a microphone shield. When a shield is used, a subparameter is whether or not clipping is used for earphone listening. When a shield is not used, the subparameter is whether an average (left) or excellent (right) earmuff is used around the earphone (Webster, 1965).

various measures of face-to-face communications in noise. Along the abscissa are most common measures of speech interference, from top to bottom: the three-band preferred octave band SIL (PSIL), based on the octaves centered at 500, 1000, and 2000 Hz; the Beranek (1947a, b) 600 to 4800 Hz SIL; the A-weighting; PNdB; C-weighting; and the AI for the 3-foot distance between talker and listener.

The figure itself is a series of noise-distance areas delineated by levels of voice used by a talker. The innovations in the figure are the "expected voice level" and the "communicating voice" level adopted by talkers when they are surrounded by ambient noise. Normal talkers don't use "normal" voice levels in a noise level of 76 dBA or 70 dB PSIL. Kryter (1946), Korn (1954), Pickett

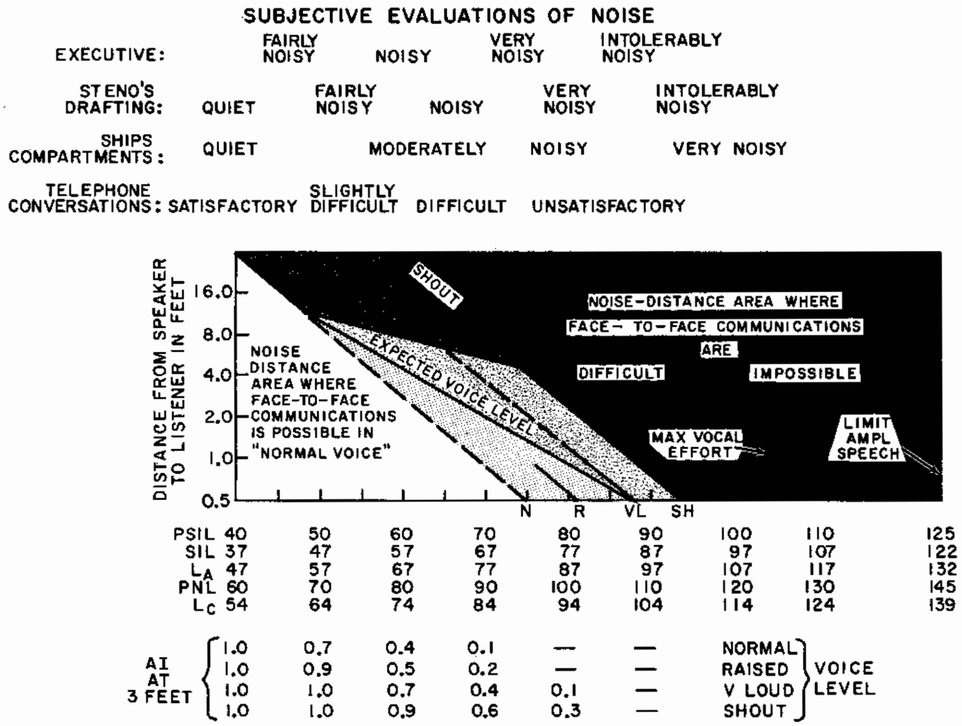

FIGURE 19. Voice level and distance between talker and listener for satisfactory face-to-face speech communication as limited by ambient noise level. Along the abscissa are various generally equivalent objective measures of noise level; the top one, and the one that varies least for predicting speech interference over various noise spectra, is the average octave band level in the octaves centered at 500, 1000 and 2000 Hz, called the *three-band preferred octave speech interference level* and abbreviated PSIL; next is SIL averaged over the three octaves from 600 to 4800 Hz; next the A-weighted sound level meter reading; next the perceived noise level (PNL) in dB; and finally, the C-weighted sound level meter reading. Below all these noise measures is the articulation index (AI) calculation for various assumed voice levels at 3 ft. Above the whole figure are various subjective evaluations for the noise levels listed below.

The figure shows that for noise levels below 40 dB PSIL satisfactory speech communication is possible in a normal voice level up to 32 ft. At noise levels less than 50 dB PSIL, most people under most conditions will speak in a "normal" voice. At levels greater than 50 dB PSIL, people unconsciously raise their voice level to compensate for the noise they are in. If communications are not vital, the "expected" voice level increase with noise level is 3 dB per 10 dB increase in noise. If communications are vital, the "communicating voice" increase is 5 dB per 10 dB increase in noise. Normally, people will not communicate above a shout, but it is possible to communicate at 6 in. in noise levels of 110 dB SIL (0.5/1/2).

To interpret the chart, assume 3 ft is the distance at which people prefer to converse. The intersection of the 3 ft distance and the "expected voice level" is roughly at a noise level of 65 dB PSIL or 71 dB L_A. This 71 dB L_A should set the top noise level acceptable to most people.

(1958), and Webster and Klumpp (1962) show that at noise levels starting somewhere around 50 dB preferred SIL, a talker's voice level increases automatically with surrounding noise level. Kryter, Korn, and Pickett's talkers increased their level 3 dB for each 10 dB increase in noise, whereas Webster and Klumpp's talkers increased their levels 5 dB for each 10 dB increase in noise. The difference was in the talker's task and amount of feedback about the effectiveness of communication. Webster and Klumpp's talkers were truly communicating with instantaneous feedback. Kryter and Pickett's talkers just read and listeners copied down answers later. In Korn's case, no objective measure of accuracy was used.

The two voice level lines labeled "communicating voice" and "expected voice level" reflect what an average talker will actually do when talking in the levels of noise indicated.

The relationship among the various measures of speech interference is open to some question, say ±1 dB. The relationships are based on samplings of noises rated by various investigators for various reasons. Table 5 summarizes these data. Four different samplings of noises, including 17 office noises, 14 aircraft noises, 19 aircraft flyover noises, and 16 very diverse but equally speech interfering noises, are listed. For each sampling the averaged value for each of five physical measurement methods is shown. Also shown is the average difference among measures over all samplings and a standard deviation measure. The standard deviation (from Klumpp and Webster, 1963) is an indication of the variation that could be expected for each measure for diverse noise spectra equated in level to be equally speech interfering. In summary, for any homogeneous (in spectra) class of noises the relationships in the table are exact. Obviously between classes of noises, office vs. aircraft for example, the relationships change slightly. The average is the best guess for all noises and the standard deviation is a measure of the reliability of the measure chosen.

The subjective noisiness of various working spaces listed above Figure 19 are derived primarily from Beranek's (1956, 1957) attempts to validate the use of his SIL and/or NC curves for rating the acceptability of office noises. The ratings of noise in ship compartments are currently unpublished data (Webster and Lepor, 1968) using the Beranek questionnaire technique on U.S. Navy ships. It is interesting to note that offices or compartments are judged on different standards, depending on many factors not directly related to the aims of this paper. For example, occupants of civilian offices include women who

TABLE 5. Relative noise levels among various measurement methods for different noise samples: (1) Beranek (1956), 17 office noises; (2) Kryter and Williams (1966), 14 aircraft noises; (3) Williams et al. (1967), 19 flyover noises; and (4) Klumpp and Webster (1963), 16 equally diverse speech-interfering noises.

	1	*2*	*3*	*4*	*Average*	*Standard Deviation*
SIL (0.5/1/2)	0	0	0	0	0	2.8
SIL (6–48)	−4	−2	−3	−2	−3	4.8
L_A	6	9	4	10	7	4.7
PNL	19	22	16	22	20	5.2
L_C	17	16	8	13	14	7.4

compare their working environment with their home environment and do not like to speak loudly. On the other hand, sailors tend to be oblivious of most noises and if it gets too noisy they can get closer together to converse. The new U. S. Navy criterion for a communicating space is 65 dB PSIL or 70 dBA, which is considerably above Beranek's office acceptability criteria. One reason for setting the criterion this high is that naval personnel have been, do, and will probably continue to communicate face-to-face in levels this high and have no real complaints. They judge their surroundings to be only "moderately noisy."

There are other ways to improve voice communication in noise, which I shall not go into in this report. Those who are interested in further details may see Kryter (1946) for a description of how to hear speech better by wearing ear plugs; Licklider and Pollack (1948) for how to improve intelligibility over electronic communication systems by distorting the speech with peak clipping; and Licklider (1948) for an introduction to advantages to be gained by using two ears and phasing speech and/or noise between them.

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Bibliography

BENSON, R. W., and HIRSH, I. J., Some variables in audio spectrometry. *J. Acoust. Soc. Amer.*, **25**, 499-505 (1953).

BERANEK, L. L., The design of speech communication systems. *Proc. Inst. Radio Engrs.*, **35**, 880-890 (1947a).

BERANEK, L. L., Airplane quieting II. Specification of acceptable noise levels. *Trans. Amer. Soc. Mech. Engrs.*, **69**, 97-100 (1947b).

BERANEK, L. L., *Acoustic Measurements*. New York: John Wiley (1949).

BERANEK, L. L., *Acoustics*, New York: McGraw Hill (1954).

BERANEK, L. L., Criteria for office quieting based on questionnaire rating studies. *J. Acoust. Soc. Amer.*, **28**, 833-852 (1956).

BERANEK, L. L., Revised criteria for noise in buildings. *Noise Control*, **3**, 19-27 (1957).

BERANEK, L. L., Reynolds, J. L., and WILSON, I. E., Apparatus and procedures for predicting ventilation system noise. *J. Acoust. Soc. Amer.*, **25**, 313-321 (1953).

BLACK, J. W., Multiple-choice intelligibility tests. *J. Speech Hearing Dis.*, **22**, 213-235 (1957).

BLACK, J. W., Contributing frequency bands in intelligibility testing. *J. Speech Hearing Res.*, **2**, 81-83 (1959).

BOTSFORD, J. H., Predicting speech interference and annoyance from A-weighted sound levels. *J. Acoust. Soc. Amer.*, **42**, 1151(a) (1967a).

BOTSFORD, J. H., Relationships of sound level to the effects of noise on people. Private communication (1967b).

CAMPBELL, G. A., Telephonic intelligibility. *Phil. Mag. Series 6*, **19**, 152-159 (1910).

COLLARD, J., Calculation of the articulation from the circuit constants. *Elect. Commun.* **8**, 141-163 (1930).

CRANDALL, I. B., The composition of speech. *Phys. Rev. Series 2*, **10**, 74-76 (1917).

DUDLEY, H., Personal communication (1968).

DUNN, H. K., and WHITE, S. D., Statistical measurements on conversational speech. *J. Acoust. Soc. Amer.*, **11**, 278-288 (1940).

DYER, W. R., The masking of speech by high- and low-pass noise. Tech. Doc. Rept. No. RADC-TDR-62-298, Rome Air Development Center (1962).

EGAN, J., Articulation testing methods. *Laryngoscope*, **58**, 955-991 (1948).

EGAN, J. P., and WIENER, F. M., On the intelligibility of bands of speech in noise. *J. Acoust. Soc. Amer.*, **18**, 435-441 (1946).

FAIRBANKS, G., Test of phonemic differentiation: The Rhyme Test. *J. Acoust. Soc. Amer.*, **30**, 596-600 (1958).

FLETCHER, H., The nature of speech and its interpretation. *Bell Sys. Tech. J.*, **1**, 129-144 (1922).

FLETCHER, H., *Speech and Hearing in Communication.* New York: Van Nostrand (1929, rev. 1953).

FLETCHER, H., and STEINBERG, J. C., Articulation testing methods. *Bell Sys. Tech. J.*, **8**, 806-854 (1929).

FRENCH, N. R., and STEINBERG, J. C., Factors governing the intelligibility of speech sounds. *J. Acoust. Soc. Amer.*, **19**, 90-119 (1947).

HAAGEN, C. H., Intelligibility measurement. *Speech Monogr.*, **13**, 4-7 (1946).

HAWLEY, M. E., and KRYTER, K. D., Effects of noise on speech. In C. M. Harris, (Ed.) *Handbook of Noise Control.* New York: McGraw-Hill (1957).

HIRSH, I. J., DAVIS, H., SILVERMAN, S. R., REYNOLDS, E. G., ELDERT, E., and BENSON, R. W., Development of materials for speech audiometry. *J. Speech Hearing Dis.* **17**, 321-337 (1952).

HOUSE, A. S., WILLIAMS, C. E., HECKER, M. H. L., and KRYTER, K. D., Articulation-testing methods: Consonantal differentiation with a closed response set. *J. Acoust. Soc. Amer.*, **37**, 158-166 (1965).

HUDGINS, C. V., HAWKINS, J. E., KARLIN, J. E., and STEVENS, S. S., The development of recorded auditory tests for measuring hearing loss for speech. *Laryngoscope*, **47**, 57-89 (1947).

International Organization for Standardization, Tech. Comm. 43, Working Group 8, Revision of Document *Noise rating for speech communication*, June (1964).

KLUMPP, R. G., and WEBSTER, J. C., Physical measurements of equally speech-interfering Navy noises. *J. Acoust. Soc. Amer.*, **35**, 1328-1338 (1963).

KORN, T. S., Effect of psychological feedback on conversational noise reduction in rooms. *J. Acoust. Soc. Amer.*, **26**, 793-794 (1954).

KRYTER, K. D., Effects of ear protective devices on the intelligibility of speech in noise. *J. Acoust. Soc. Amer.*, **18**, 413-417 (1946).

KRYTER, K. D., The effects of noise on man. *J. Speech Hearing Dis.*, Monogr. Suppl. 1 (1950).

KRYTER, K. D., The meaning and measurement of perceived noise level. *Noise Control 6*, **5**, 12-27 (1960).

KRYTER, K. D., Methods for the calculation and use of the articulation index. *J. Acoust. Soc, Amer.*, **34**, 1689-1697 (1962a).

KRYTER, K. D., Validation of the articulation index. *J. Acoust. Soc. Amer.*, **34**, 1698-1702 (1962b).

KRYTER, K. D., and WILLIAMS, C. E., Masking of speech by aircraft noise. *J. Acoust. Soc. Amer.*, **39**, 138-150 (1966).

LICKLIDER, J. C. R., The influence of interaural phase relations upon the masking of speech by white noise. *J. Acoust. Soc. Amer.*, **20**, 150-159 (1948).

LICKLIDER, J. C. R., Three auditory theories. In S. Koch (Ed.) *Psychology: A Study of a Science, Study 1: Conceptiual and Systematic, 1. Sensory, Perceptual and Physiological Formulation.* New York: McGraw-Hill (1959).

LICKLIDER, J. C. R., and POLLACK, I., Effects of differentation, integration, and infinite peak clipping upon the intelligibility of speech. *J. Acoust. Soc. Amer.*, **20**, 42-51 (1948).

MILLER, G. A., The masking of speech. *Psychol. Bull.*, **44**, 105-129 (1947).

PICKETT, J. M., Effects of vocal force on the intelligibility of speech sounds. *J. Acoust. Soc. Amer.*, **28**, 902-905 (1956).

PICKETT, J. M., Limits of direct speech communication in noise. *J. Acoust. Soc. Amer.*, **30**, 278-281 (1958).

PICKETT, J. M., and KRYTER, K. D., Prediction of speech intelligibility in noise. Air Force Cambridge Research Center Tech. Rept. 55-4 (1955).

POLLACK, I., Effects of high pass and low pass filtering on the intelligibility of speech in noise. *J. Acoust. Soc. Amer.*, **20**, 259-266 (1948).

RAYLEIGH, LORD, Acoustical notes—VIII, *Phil. Mag., 6th series*, **16**, 235-246 (1908).

ROSENBLITH, W. A., and STEVENS, K. N., *Handbook of Acoustic Noise Control*, Vol. II, *Noise and Man*. Wright Air Development Center, WADC Tech. Rept. 52-204 (1953).

RUDMOSE, H. W., CLARK, K. C., CARLSON, R. D., EISENSTEIN, J. C., and WALKER, R. A., Voice measurements with an audio spectrometer. *J. Acoust. Soc. Amer.*, **20**, 503-512 (1948).

SPEAKS, C., Intelligibility of filtered synthetic sentences. *J. Speech Hearing Res.*, **10**, 289-298 (1967).

STEINBERG, J. C., Effects of distortion upon the recognition of speech sounds. *J. Acoust. Soc. Amer.*, **1**, 121-137 (1929).

STEVENS, S. S., and DAVIS, H., *Hearing, its Psychology and Physiology*. New York: John Wiley (1938).

STEVENS, S. S., MILLER, J., and TRUSCOTT, I., The masking of speech by sine waves, square waves, and regular and modulated pulses. *J. Acoust. Soc. Amer.*, **18**, 418-424 (1946).

STRASBERG, M., Criteria for setting airborne noise level limits in shipboard spaces. Bureau of Ships Rept. No. 371-N-12 (1962).

WEBSTER, J. C., Generalized speech-interference contours. *J. Speech Hearing Res.*, **7**, 133-140 (1964a).

WEBSTER, J. C., Relations between speech-interference contours and idealized articulation index contours. *J. Acoust. Soc. Amer.*, **36**, 1662-1669 (1964b).

WEBSTER, J. C., Important frequencies in noise-masked speech. *Arch. Otolaryng.*, **80**, 494-504 (1964c).

WEBSTER, J. C., Speech communications as limited by ambient noise. *J. Acoust. Soc. Amer.*, **37**, 692-699 (1965).

WEBSTER, J. C., and KLUMPP, R. G., Effects of ambient noise and nearby talkers on a face-to-face communication task. *J. Acoust. Soc. Amer.*, **34**, 936-941 (1962).

WEBSTER, J. C., and KLUMPP, R. G., Artciulation index and average curve-fitting methods of predicting speech interference. *J. Acoust. Soc. Amer.*, **35**, 1339-1344 (1963).

WEBSTER, J. C., and LEPOR, M., Noise, you get used to it. *J. Acoust. Soc. Amer.*, **44**, (1968).

WESTERN ELECTRO-ACOUSTICS LABORATORY, Study and investigation of specialized electro-acoustic transducers for voice communication. Contract No. AF33(616)-3710, Task No. 43060 (1959).

WILLIAMS, C. E., and HECKER, H. H. L., Selecting an intelligibility test for communication systems evaluation. *J. Acoust. Soc. Amer.*, **42**, 1198(A) (1967).

WILLIAMS, C. E., STEVENS, K. N., HECKER, M. H. L., and PEARSONS, K. S., The speech interfering effects of aircraft noise. Federal Aviation Administration Tech. Report FAA DS-67-19. September (1967).

YOUNG, R. W., Don't forget the simple sound-level meter. *Noise Control*, **4**, 42-43 (1958).

YOUNG, R. W., Single-number criteria for room noise. *J. Acoust. Soc. Amer.*, **36**, 289-295 (1964).

ZOLDAKOV, I. V., The determination of speech intelligibility in a channel with a limited frequency band. *IZV Electropromyshl. slab. Toka, NO12*, 32-41 (translation issued by Great Britain, Ministry of Supply, TPA3 Technical Information Bureau as T-2266) (1940).

Effects of Noise on Psychological State

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Psychological state is a complex of many processes including sensations, perceptions, actions, thoughts, feelings, attitudes, needs, and motives. All of these processes find expression in man's behavior and subjective experience. Noise, or unwanted sound, in interacting with these processes may have adverse effects resulting in losses in work performance, sleep disruption, annoyance, and irritability (Broadbent, 1957; Broadbent and Burns, 1965; Wilson, 1963). Such noise-induced disturbances are the subject of this presentation. More specifically, the effects of noise on the different component processes of psychological state will be treated here as they may bear on one's ability to cope with job or task demands, or to attain comfort, rest, and well-being.

Noise Effects on Sensory and Perceptual Processes

Losses in hearing sensitivity, both temporary and permanent, together with the masking of speech and other desired sounds, constitute the most significant sensation and perception problems posed by noise (Kryter, 1950; Bell, 1966). Different aspects of noise-induced hearing loss and speech interference have been alluded to in this conference by Ward and Webster. However, one must add how listening difficulties relate to problems of work performance and general annoyance. Obviously, losses in hearing ability for sounds critical to a worker's task or lack of adequate speech communication can degrade efficiency on those jobs having such requirements. In this regard, office workers, having varying needs for speech communication in their jobs, were found to rate the severity of noise disturbance in nearly direct relation to the amount of voice communication they believed was necessary for effective performance (Beranek, 1956). Inability to hear auditory warning signals or shouts of caution because of noise has also been implicated in industrial accidents (Wilson, 1963). While plausible, data indicating the significance of this problem are lacking.

Aside from considerations of job performance, the masking of speech by noise is a determinant of annoyance and one measure of this masking, the speech-interference-level (SIL), has been shown to be a gauge of complaints to noise-intrusion in communities.[1] In an early survey of airport noise problems in residential areas near military air bases, the annoyance reactions of the residents were found to be keyed to the amount of time that the aircraft noise exceeded certain specified SIL values (Borsky, 1958). Over 50% of the persons interviewed complained of frequent disturbance and annoyance from aircraft noise when an SIL value of 60 dB (dB in sound-pressure level re 0.0002 microbar), measured outdoors, was exceeded for at least 80 sec per hour. Only 15% reported such frequent disturbance where an SIL of 60 dB was attained less than 20 sec per hour. An SIL of 60 dB would pose some difficulty in telephone use and would require raising the voice in order to have intelligible conversation for talker-listener distances of 3 ft, and a loud voice for talker-listener distances of 7 ft.

The penetration of outdoor noises into school buildings and churches has created serious disturbance and annoyance reactions, again owing largely to problems of speech interference. In describing such problems caused by aircraft noise in his school district, one school superintendent reported 40 to 60 interruptions per day in classroom listening activities of three schools lying within 1.5 mi of a major commercial airport. From 10 min to 20 min per day were lost in each classroom because of this aircraft noise intrusion. Summing this time for the total number of affected classes yielded a cumulative loss of from 700 min to 1400 min per day of instruction time (Committee on Interstate and Foreign Commerce, 1959-1962, p. 234). Schools and church buildings near airports or expressways have required additional acoustic insulation in order to cope with the noises radiating from these transportation facilities.

Noise has effects on nonauditory sensory and perceptual experience which deserve mention in light of performance problems. The more positive conclusions about the adverse effects of noise on task performance have come from laboratory studies of vigilance in which the subject is required to maintain a watch over numerous dials any one of which may show a faint signal deflection at any time (Broadbent, 1957; Jerison and Wing, 1957). The number of signals correctly detected and the speed of response provide measures of performance on this task, and both of these measures reveal losses in high-level noise (see Figure 1). Two main theories to explain noise disruption of this perceptual task have been offered: one suggests that noise causes brief lapses in attention to the relevant stimulus information (Broadbent, 1957); the other proposes that noise may cause conditions of cortical over-arousal with resultant loss in behavioral control (Broadbent, 1957; Carpenter, 1962).

Noise effects on vigilance are especially important because of their relevance

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[1] Speech-interference-level (SIL) is a measure which depicts the ability of a noise to mask speech. It was originally determined by simply averaging the sound levels found in 3 octave bands of the masking noise, namely, 600-1200, 1200-2400, and 2400-4800 Hz. With the newer midfrequency scheme for designating octave bands, SIL now is generally the average of octave bands centered at 500, 1000, and 2000 Hz. Functions describing vocal effort and talker-listener distances needed for intelligible speech communication, given different SIL noise conditions, have been formulated (Peterson & Gross, 1967).

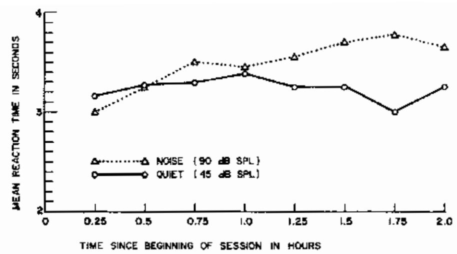

Figure 1. Mean reaction time to an occasional faint visual signal in two levels of noise (from Broadbent, 1957).

to job situations involving monitoring and watchkeeping. In fact, an early industrial study of a vigilance task found that performance improved with a reduction in noise level (Carpenter, 1962, 1964). In this instance, cotton weavers, who supervised the operation of a number of largely automatic machines, had to be constantly alert for stoppages due to thread breakage. Such stoppages required quick detection and repair to get a machine back into operation without undue delay. Reducing noise level through the use of earplugs caused an estimated improvement in individual worker efficiency of about 12%. A more recent study involving monitoring of film-perforating machines also showed an increase in job efficiency for workers when they were in the quieter of two working environments (cited by Carpenter, 1962, 1964).

Other nonaural sensory functions affected by noise are balance and certain aspects of visual accommodation. Nixon, Harris, and von Gierke (1966) found that equilibrium—measured by standing on rails of different width—was impaired by exposure to wide-band noise at overall levels of 120 dB. This disturbance of balance was clearly evident for unequal noise stimulation of the two ears. Another study revealed that high-level noise reduced the speed with which the eye could move through certain angles and focus clearly on near and distant objects (Stevens, 1941). This result was believed due to noise affecting the ciliary muscles which control the lens of the eye. These and other noise-induced changes in vestibular and visual functions are sometimes dismissed as having little practical importance because generally high noise levels are needed to produce such effects and/or the magnitude of the resultant effect is quite small. However, noise levels in military and industrial environments have risen sharply with the introduction of more powerful tools and power sources, to where they are comparable if not higher than the levels used in the above laboratory studies. For example, the octave-band levels used in the previously mentioned noise and balance study are slightly less than similar spectral values of noise measured at the ears of quarry workers using oxygen torches, and at the ears of metal miners operating jumbo rock drilling equipment (see Figure 2). While the disturbances of these mining and quarrying noise levels on balance and vision might still be small, the many hazards inherent to these occupations may make such effects tragically significant. Indeed, mining and quarrying are among those industries having the highest accident and injury rates per man-hours of work (National Safety Council, 1967).

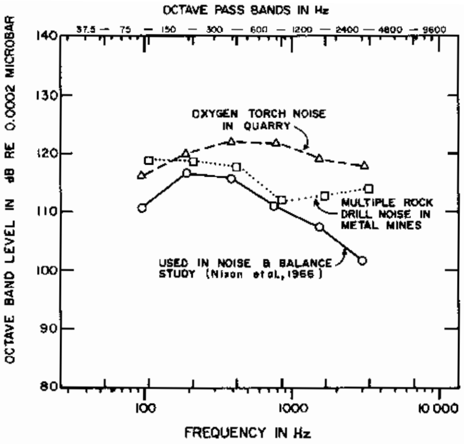

Figure 2. Octave-band sound-pressure levels in dB for the noise found at the ear of a quarry worker with an oxygen torch, a metal miner operating a multiple rock drill (jumbo) and employed in the noise-balance study of Nixon et al. (1966).

Noise Effects on Action and Thought Processes

Attempts to show detrimental effects of noise on mental and psychomotor abilities have failed to yield well-defined conclusions. Studies of performance in noise on mental tasks involving arithmetic computations, mechanical and abstract reasoning, clerical sorting and coding, and on psychomotor tasks of reaction time and tracking sometimes show losses, sometimes improvement, and in most cases no significant change when compared to performance under nonnoise conditions (Broadbent, 1957; Kryter, 1950; Corso, 1951). These conflicting findings are due, in part, to differences in the nature of the noise or the task conditions used in these assorted evaluations, and the analytical techniques applied in appraising observed effects. For example, noise-induced loss in performance is most frequently reported in those studies employing noise conditions in excess of 90 dB; those studies using less intense conditions rarely show any noise decrements (Woodhead, 1964; Broadbent, 1957). Further, aperiodic intermittent noises or random bursts of sound appear more likely to disrupt performance than steady-state continuous noise. The apparent losses for the transient cases are largely confined to brief time periods immediately following the change in noise level or the occurrence of a sound burst (Woodhead, 1959; Fornwalt, 1965). Also of note is that the disruptive effects of noise might be specific to some, but not all, aspects of a given task. This was illustrated in a study by Woodhead (1964) involving a two-phase task in which subjects first had to memorize a six-digit number (memory phase), and then subtract from it a four-digit number (calculation phase). The occurrence of noise during the memory phase of this task tended to produce more errors in the subsequent calculation. In contrast, the occurrence of noise in just the calculation phase seemed to facilitate overall performance.

Still other, more general, aspects of noise effects on performance are beginning to emerge: (1) It appears that noise is more inclined to disturb the quality rather than the quantity of work (Carpenter, 1962; Fornwalt, 1965), that is, noise might not alter the total number of responses made or the total work output, but may cause more errors. Some laboratory studies suggest that the losses in the quality of work may be due to subjects working faster (and presumably more carelessly) in the hope that a stressful situation can be ended that much sooner. For example, astronauts, upon being exposed to 145-dB sounds from a jet engine at full thrust, experienced difficulty in carrying out simple arithmetical operations and tended to put down any answer in order to end the experiment quickly (Bell, 1966). (2) Performance under noise is subject to marked fluctations, periods of poor performance being interwoven with periods of heightened effort (Broadbent, 1957). These performance oscillations when summed across the total session yield little or no overall performance change (see Figure 3). (3) Noise is most likely to impair performance of those tasks that place extreme demands on the worker (Boggs and Simon, 1968). Simple tests of performance under noise demand less than the total capacity of the individual. Noise disturbances in these situations can thus be overcome by the subject's drawing upon his reserve capacity. However, if the task is one requiring continual and unremitting attention and effort, the intrusion of noise has adverse consequences. The vigilance task, previously noted, has such features. Another task, serial reactions, also falls into this category. In this latter test, the subject observes a group of lights arranged in a spatial pattern. Each light is paired with a response button, and the subject has to press the button corresponding to the light which is on. Each response changes the display by bringing on another light. The subject thus performs as fast as possible for periods of usually 30 min in length. Noise has no apparent effect on the total responses made but it does increase errors (error being defined as pressing the wrong button for a given light). Noise also causes gaps in responding, periods of 1.5 sec or longer in which no response is made (Broadbent, 1957; Carpenter, 1962). These two results exemplify the poor quality and variable performance effects mentioned above.

On the positive side, rhythmic noise occurrences may pace performance and accentuate movements or other required actions that are in phase with the noise. Such dynamogenic effects can serve to sustain performance on jobs that might be physically tiring. Noise might also prove beneficial to jobs which are simple and repetitive in nature. Noise may mask stray distracting sounds or

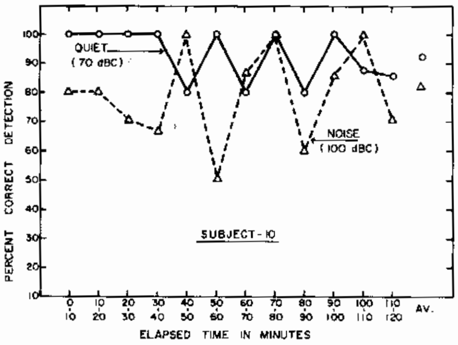

FIGURE 3. Individual subject performance on a detection task under two levels of noise.

supply added stimulation enabling the subject to remain alert or aroused in a task that is otherwise monotonous or boring (Wilbanks, Webb, and Tolhurst, 1956). In this context, it was recently noted that music programmed to become increasingly livelier maintained if not facilitated reaction-time measures throughout the course of a visual detection task (Wokoun, 1968). A musical program containing the same melodies but presented in reverse order (i.e., decreasing liveliness) showed relatively slower response times, during the same session of testing, for a matched test group. These findings suggest that more stimulating music in industries should be played toward the latter part of the work day or shift when there is a tendency for decreased work output.

A major shortcoming in studying noise effects on performance, especially under laboratory conditions, is that the experimental situation often fails to depict the real life situation in which the average person works well below his maximum efficiency and responds to many stimuli besides noise. Further, laboratory tasks are usually novel in nature and the time spent in the noise-performance test sessions is quite limited. More long-term study of possible behavioral changes consequent to manipulations of noise found in actual work environments is needed since questions remain: Do noise exposures produce decrements in work performance? Do they have other manifestations such as increased accidents, absenteeism, and labor turnover? Processes of adaptation to noise could also be evaluated in these long-term studies as they may affect work efficiency and other considerations, such as energy expenditure. Short-term adaptation effects, reflected by initial performance losses in noise and subsequent improvement, are frequently noted in laboratory studies (Teichner, Arees and Reilly, 1963). Aspects of adaptation, given months or years of experience in noisy environments, need to be described.

In another vein, the problem of adaptation to noise has been the subject of much discussion dealing with the startle response induced by sudden loud sounds such as a sonic boom (Kryter, 1966; Nixon, 1965). Laboratory studies do show diminished levels of startle reaction to recurring boom-like sounds, which is presumed to reflect adaptation; but the absence of a real life context makes such findings suspect (Kryter, 1966). On the other hand, Air Force experience shows that communities impacted regularly by sonic booms from supersonic military aircraft show accommodation to these disturbances (Nixon, 1965). Any unusual boom occurrence, however, can trigger increased community reactions. In a study of startle reactions in animals produced by gunshot-like sounds it was found that the background acoustic environment influenced the strength of responses and their adaptation (Hoffman and Fleshler, 1963). Startle responses were stronger against a background of moderate-level, steady-state noise than they were in a quiet background or in one containing moderate-level pulses. The fact that less intense startle reactions occurred under quiet conditions is somewhat surprising in view of the notion that the presence of significant background noise may increase tolerance toward the intrusion of still higher-level sounds (Parrack, 1957).

Noise Effects on Attitudes and Feelings

Certain kinds of noises or sounds directly affect feelings and attitudes. This can be illustrated in various ways: (1) The sound of chalk scraping on a blackboard or other abrasive types of noise can cause chill-like feelings in the listener. (This experience, though commonly reported for this type of stimulation, has received little research attention.) (2) Musical sounds, by varying rhythm, tempo, and melody, can evoke moods ranging from calmness and contentment to those of excitement and elation. Accordingly, music has been used as an adjunct to the psychotherapeutic process: more stimulating types of music serving to excite depressed patients, and less stimulating forms being used to relax or calm agitated patients (Stein, 1963). (3) Music in industry seems to create positive attitudes in many employees toward their work whether or not it has any significant effects on their productive output (Uhrbrock, 1961).

Noise and sounds also can indirectly influence attitudes and feelings by virtue of the information being conveyed. These indirect influences are of prime importance when considering problems of noise annoyance. For example, many sounds are judged annoying not because of their acoustic properties, but because they convey distress, alarm, and other unpleasant meanings. In a survey of noise conditions in hospitals it was found that the second most prevalent source of annoyance was staff conversation in the halls (Goodfriend and Cardinell, 1963). Interviews with patients indicated that these sounds were objectionable not because of their loudness but because of the information communicated, such as descriptions of other patients' conditions, operations, and symptoms. The third most frequent source of noise annoyance in the hospitals surveyed was the sound of other patients in distress, moaning or calling for a nurse.

To cite another example, the sound of approaching aircraft, because of the possibility of a crash, can elicit fear, and this fear appears to be a factor motivating complaints of annoyance in neighborhoods near airports (Borsky, 1958; Parrack, 1957).

Similarly, the screaming siren of a patrol car or the clanging bells of a fire engine, because of their purposes, can engender annoyance out of fear.

Thus, unpleasant feelings or attitudes about certain sounds based on their information content can lead to annoyance which might be altogether out of proportion to the physical characteristics of the sound. These associations and still others, such as the necessity or advantage identified with certain sources of noise (e.g., garbage disposal, lawn mower), hopelessly complicate the development of any acoustic scale for depicting noise annoyance on an absolute basis. These considerations also make it quite clear that there are no practical means for freeing everyone from the annoyance problems caused by noise.

As for the noise stimulus itself, some properties of sound are more annoying than others. In general: (1) Annoyance grows with the increasing intensity of sounds (i.e., increasing loudness). (2) Annoyance is greater for those sounds of higher frequency (higher pitch). (3) Sounds which are variable in nature, i.e., occurring randomly in time or changing in level and point of origin, are judged more annoying than those which are unchanging.

There has been intense interest in identifying a measure of noise that can best quantify its objectionability or annoyance. Spectral conversions into loudness in sones or phons as described by Zwicker and Stevens (Broch, 1962), or into perceived noise level in decibels (PNdB) as developed by Kryter (1968) have been offered for this purpose. So too has A-scale level in dB read directly from a conventional sound-level meter (Mills and Robinson, 1961). These measures essentially provide weighting schemes which, in various ways, take into account established relationships between different acoustic dimensions of the noise stimulus and associated auditory reactions. PNdB values have been found to agree with subjective ratings of the acceptability of aircraft flyover noises (Kryter, 1968; Kryter and Pearsons, 1963) and some major domestic and foreign airports have adopted noise-control criteria using this measure. Loudness determinations and A-scale readings closely correlate with subjective reactions to motor vehicle noise (Mills and Robinson, 1961; Robinson, 1962; Galloway, 1962). A-scale limits have been incorporated into state ordinances for governing the noise emissions of motor vehicles on state roads[2] (Galloway, 1962); loudness measures have been used to gauge possible annoyance problems associated with proposed highway construction near residential areas (Ostergaard and Donley, 1963). Finding a standard for noise annoyance evaluation would seem a desired goal here. One preliminary attempt, several years ago, to determine the degree to which one may generalize different measures to index noise annoyance for assorted transportation noises, found loudness measures to bear the closest correspondence with subjective objectionability ratings, followed by PNdB, and A-scale measures (see Figure 4). Kryter (1968) has since refined PNdB calculations by including added exposure variables, and has shown the applicability of this measure in rating outdoor and indoor noise problems of both an annoyance and hearing hazard nature.

Granted that noise causes annoyance, might not mental or nervous illness result or be aggravated from prolonged or recurring types of noise exposure? Presently, sketchy and inconsistent findings do not permit an answer to this question. For example, a British report notes that inquiries of doctors with offices in the vicinity of a major airport revealed that only one patient had a mental disorder attributed by his physician to aircraft noise exposure (Wilson, 1963). Prolonged high-level noise exposures found in heavy industry have given some indication of increased mental stress and maladjustment among workers. Jansen (1959), in evaluating the effects of noise on steelworkers, found that those in the noisiest work places had a greater frequency of social conflicts both at home and in the plant. Michalova and Hrubes, in an unpublished study, noted increasing signs of chronic fatigue and neurotic

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[2] State of California, Department of California Highway Patrol, Vehicle Code, Vehicle noise measurement regulations. Art. 10, Subch. 4 (1968).

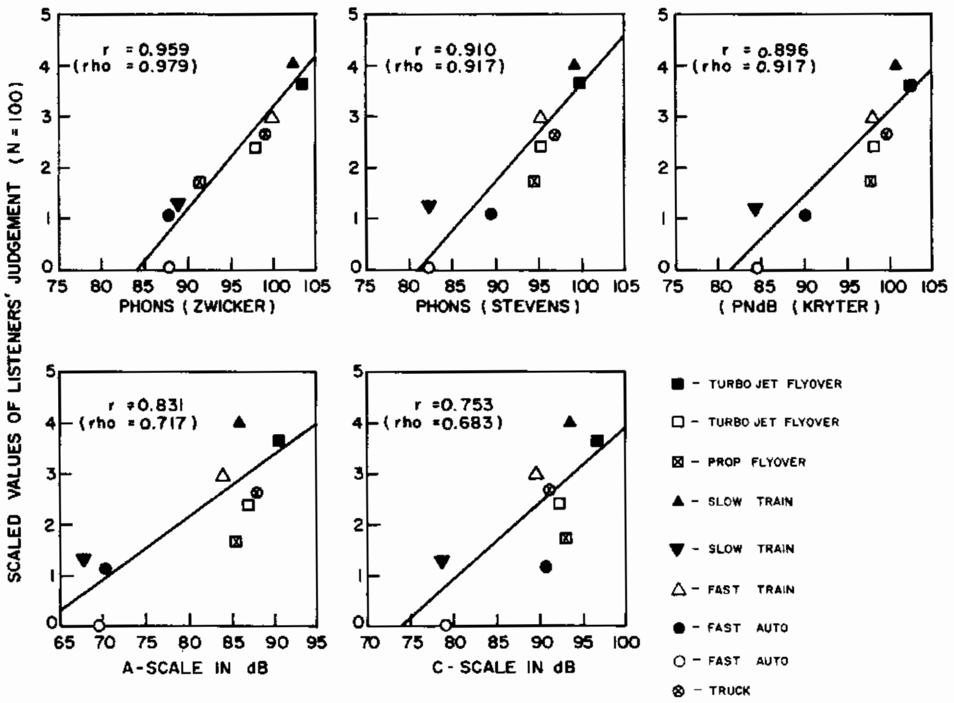

FIGURE 4. Correlations between scaled objectionability ratings for recorded samples of assorted transportation noises and different proposed noise annoyance measures. The scaled ratings were obtained from paired-comparisons procedures in which subjects judged which of the two noises in a given pair was more objectionable. All possible pairings of the noises specified were presented with the order of presentation of the noises in the different pairs being counterbalanced across the listener group (Cohen and Scherger, 1964).

complaints in workers who were exposed daily to noise levels over 110 dB. Nevertheless, causal relations between noise and psychosocial problems are difficult to prove from such studies because of the possibility of numerous confounding factors. Psychiatric interviews and psychological tests on crew members of a U.S. aircraft carrier uncovered no unusual mental problems even though the men worked and lived under continual high-level noise conditions (Wilson, 1963). The fact that the aircraft carrier crews are a select group, well-trained, and hardened for combat operations—that is, their uniqueness—might restrict any generalizations from this finding. Yet one still wonders about the possible mental stress caused by noise in other special groups such as hospital or convalescent and rest home populations. Would, for example, better noise exclusion in hospital wards hasten recovery time of the sick?

Attitudes and feelings about noise are primarily responsible for much of the individual differences observed in studying noise effects on performance and aspects of annoyance. A study by Mech (1953) showed that performance in noise could be altered by different pretest briefings given to the subjects about the possible effects of noise on their work efficiency. The group expecting noise to cause some decrement did in fact show loss, whereas the group expecting noise to improve performance showed a performance gain. This finding is particularly important in view of the widely held belief that noise, even of moderate levels, can impair performance. If a person feels that noise will cause him to work slowly or inefficiently, then he perceives his work as slow and inefficient, despite the experimental evidence.

Personality factors may also underlie individual differences in noise effects on performance. In a vigilance study conducted under various noise conditions (Cohen, Hummel, Turner, and Dukes-Dobos, 1966), subjects who showed the poorest performance under higher levels of noise were those revealing greater anxiety and neurotic tendencies, determined by a personality questionnaire (see Table 1). Introversion was also shown to be associated with poor performance under these test conditions.

Attitudes and feelings have still other ramifications for noise performance and noise annoyance evaluations. Factors of morale or ego-involvement in one's job, for example, have been found to override possible performance problems caused by noise, heat, or other environmental stresses (Felton and Spencer, 1961). Similarly, being convenient to transportation facilities might, for some individuals, outweigh the attendant noise disturbances.

TABLE 1. Comparison of mean vigilance scores (percentage correct detections) for 12 "most normal" and 12 "most deviant" subjects on the Personality Measures for Each Background Noise Condition (Cohen et al., 1966).

Background Noise Condition	*Personality Grouping*	*Anxiety (Welsh)*	*Neuroticism (Winne)*	*Manifest Anxiety (Taylor)*	*Psycho-asthenia*	*Intro-version*
Control	Normal	94.00	92.71	93.09	93.75	94.11
	Deviant	93.00	94.70	92.78	95.58	92.27
	Difference	1.00	−1.99	0.31	−1.83	1.84
High Level	Normal	96.00	95.00	94.90	95.65	93.46
	Deviant	93.00	92.41	91.51	95.01	87.93
	Difference	3.00	2.59	3.39	0.64	5.53
Variable	Normal	94.00	94.70	95.51	95.63	94.66
	Deviant	93.00	92.72	89.19	93.50	88.39
	Difference	1.00	1.98	6.32	2.13	5.27

Noise Effects on Needs and Motivation

The need for privacy, relaxation, rest, and sleep cannot be seriously questioned but much remains to be learned about these states. For example, rest and sleep presumably provide the conditions required for the restitution of body energy and recovery from fatigue. It is still unclear, however, why humans need as much sleep as they do. The effects of prolonged sleep deprivation are well known: losses in mental and physical functioning, irritability, hallucinatory tendencies, and idea confusion (Berger and Oswald, 1962). However, still to be evaluated are behavioral and other problems that might be caused by limiting daily periods of sleep. Results here as opposed to total deprivation would probably be more meaningful for evaluating sleep disturbances caused by noise. Aspects of relaxation also need to be investigated since change of stimulation, rather than peace and quiet, might be the desired goal. Some office workers at the end of the day, for example, find pleasure in a heated game of handball or some other equally strenuous activity. Sensory isolation experiments have revealed stress effects and have highlighted man's needs for varying stimulation (Fiske, 1961).

In any case, it is quite evident that noise can frustrate desires for privacy, rest, relaxation, and sleep. For example, surveys of communities impacted by significant subsonic and supersonic aircraft flyover noise have found that the interruption of rest, relaxation, and sleep are the major underlying causes of registered complaints, and that such complaints grow with increasing amounts of aircraft noise exposure (Wilson, 1963; Nixon, 1965).

Surveys dealing with noise conditions in towns have found roadway traffic to be the major source of noise disturbances; and more people are affected by traffic noises when they are at home than when they are outdoors or at work. This fact, that people are more disturbed by traffic noises at home than elsewhere, would suggest that their needs for peace and quiet are unmet (Wilson, 1963).

Indoor noises are also sources of disturbance to privacy and rest. A recent survey of reactions to general living conditions in new garden-type apartments found that interior noises, such as from banging doors, plumbing, garbage disposals, and other appliances, generate complaints (National Association Home Builders Research Foundation, 1967). Despite probable differences in sound levels, some of the noises (e.g., garbage disposal, plumbing) proved more bothersome when they came from a neighbor's apartment than from one's own (see Table 2). Invasion of one's privacy would seem to be the basis for the difference in these complaints.

From another standpoint, consideration of the psychological and social stresses suffered by the occupants of buildings which lack acoustical privacy must not be overlooked. Most apartment dwellers naturally are under considerable constraint if they are aware that their next door neighbor can hear them. Living under such conditions can be most trying for the occupants because any careless outburst of speech or activity might cause them extreme embarrassment or discomfort. In this regard, conversations transmitted through adjoining bedrooms of different apartments and plumbing noises may be the cause of the greatest uneasiness to the occupants of apartments than perhaps any other household sounds or noises. In short, living in a "sound-porous fishbowl" is distressing.

Field studies have shown that much greater annoyance results when sleep and rest are disturbed than when only talking or listening activities are

TABLE 2. Percentage of apartment occupants finding specified indoor noises bothersome.* (Nat'l Assn. Home Builders Research Foundation, 1967)

Type of Noise	Point of Origin: Adjacent or Upstairs Apartment	Point of Origin: From Own Apartment
Plumbing	71.0	13.0
Garbage Disposal	73.1	32.0
Dishwasher	42.3	68.0
Doors Slamming	86.5	—
Walking	50.0	—
TV and Radio	7.0	—
Phone Ringing	1.0	—
Noises from Bedroom (Conversation, Baby Crying)	10.0	—
Talking in Halls, on Stairs, and on Landings	17.0	—

* Percentage based on 78–98 respondents sampling 78 different apartment units.

interrupted (Borsky, 1958). This finding plus the health significance attributed to rest and sleep suggest that criteria for annoyance be based on noise-induced disturbances to sleep. However, research data immediately relevant to the identification of noise or sound levels capable of disrupting sleep are not extensive. A preliminary study by Kryter (1966), for example, determined the minimum sound levels at which assorted pure-tone sounds and aircraft flyover noises could alter the electroencephalogram (EEG) patterns characteristic of different stages of sleep and could ultimately awaken the subject. For the deeper stages of sleep, increasing the sound level by as much as 80 to 90 decibels above the awake threshold level often caused no change in the EEG pattern. Further, once a change could be induced by a given sound, several presentations of the sound were needed at even higher levels to finally awaken the sleeper. For the lighter stages of sleep, there was a significant change in EEG response when the sound level was only 30 to 40 dB above the awake threshold levels. Further highlighting this variance in sound levels for sleep disturbance, Steinicke (Grandjean, undated) presented different levels of 50-5000 Hz noise for 3-min periods between 2 A.M. and 7 A.M. to over 300 sleeping subjects. From 10 to 20% of the group were awakened under noise conditions equivalent to a loudness level of 35 phons, while some were still asleep when the noise level reached 70 phons. A noise of 45 phons awakened 50% of the subjects, and this loudness level has been used in Germany as a standard for the quietness of sleeping places (Broadbent and Burns, 1965). Currently, some Canadian investigators are studying interference in sleep processes caused by motor vehicle and other sounds at different levels in order to derive criteria for controlling community noise (Thiessen and Olson, 1968).

Still other problems need study relevant to criteria setting for noise-induced sleep disturbance. The question remains, whether interference by noise of

EEG patterns, rapid eye movements (REM), and other physiologic measures characteristic of different sleep stages might have some adverse effects, even if the slumberer is not consciously awakened by the noise. Dement (1966) has noted that greater irritability, tiredness, and difficulty in concentration follow disruptions of the REM stages of sleep than after sleep disturbances outside these REM periods. He theorizes that REM activities denote dreaming, which has need-fulfillment value.

Aspects of adaptation to noise with regard to sleep disturbance also need to be evaluated. Common experience has found that the city dweller, frequently encountering significant levels of outdoor and indoor noise, becomes accustomed to such exposures and can sleep in their presence. The same individual vacationing in the quiet atmosphere of the country finds it difficult to sleep because of the background of cricket noise. The degree of familiarity or meaningfulness of the noise has a considerable effect on its disturbing quality.

Discussion

Reported adverse effects of noise on man's behavior and subjective experience include the following: (1) losses in work capacity, (2) disruption of rest and sleep, (3) annoyance reactions, and (4) general mental distress. This discussion has treated these various problems by describing interactions between noise and different psychologic processes such as perception, attitudes, thoughts, and needs. The complexity and variability inherent in evaluating noise-induced disturbances in behavior has been noted. Although performance loss in noise might be traced to impairments in certain perceptual, psychomotor, or mental functions, it can be greatly affected by one's attitudes about noise, personality factors, or ego-involvement in one's work. Noise annoyance, reflected in negative feelings and attitudes, can be shaped not only by the qualitative and quantitative features of the acoustic stimulus but also by the information conveyed by such sounds. Annoyance caused by noise intrusion may also accrue from frustrated attempts to communicate, or to attain privacy, to rest, or to sleep.

The dynamic nature of some of the behavioral functions disrupted by noise (e.g., sleep) plus aspects of adaptation contribute greatly to the variability of human response in this problem area and further complicate the establishment of criteria to alleviate noise disturbances. Obviously, some individuals will receive no relief from noise, irrespective of the limits chosen. Information is particularly lacking on the possible behavioral and mental health consequences of long-term, chronic noise exposures.

References

Bell, A., *Noise, an Occupational Hazard and Public Nuisance. Publ. Hlth. Paper No. 30* Geneva: World Health Organization, (1966).

Beranek, L. L., Criteria for office quieting based on questionnaire rating studies. *J. acoust. Soc. Amer.*, **28**, 833-852 (1956).

Berger, R. J., and Oswald, I., Effects of sleep deprivation on behavior, subsequent sleep, and dreaming, *J. ment. Sci.*, **108**, 457-465 (1962).

Boggs, D. H., and Simon, J. R., Differential effect of noise on tasks of varying complexity. *J. appl. Psychol.*, **52**, 148-153 (1968).

Borsky, P., Some of the human factors underlying community reactions to Air Force noise. Paper read at 6th Annual Meeting of Armed Forces. Washington, D. C.: Nat. Res. Council Comm. on Hearing and Bioacoustics (CHABA) (1958).

Broadbent, D. E., Effects of noise on behavior. In Ch. 10 of C. M. Harris (Ed.), *Handbook of Noise Control.* New York: McGraw-Hill (1957).

Broadbent, D. E., and Burns, W., Effects of noise on hearing and performance. *Rep. 65-1057.* London: Minist. Def. Med. Res. Coun. (1965).

Broch, J. T., Loudness evaluation: A review of current methods. B. & K. Tech. Rev. No. 2 (1962).

Carpenter, A., Effects of noise on performance and productivity. *Control of Noise.* Sympos. No. 12, 297-310, London: H. M. Station. Off. (1962).

Carpenter, A., How does noise affect the individual? *Impulse,* **24** (1964).

Cohen, A., and Scherger, R. F., *Correlation of Objectionability Ratings of Noise with Proposed Noise-Annoyance Measures.* Tech. Rep. RR-3, Cincinnati, Ohio: Publ. Hlth. Serv., Div. Occupa. Hlth. (1964).

Cohen, A., Hummel, W. F., Turner, J. W., and Dukes-Dobos, F. N., *Effects of Noise on Task Performance.* Tech. Rep. RR-4, Cincinnati, Ohio: Publ. Hlth Serv., Div. Occup. Hlth. (1966).

Committee on Interstate and Foreign Commerce, *Hearings on Airport Noise Problems.* 234 (1959-1962).

Corso, J. F., *The Effects of Noise on Human Behavior.* WADC Tech. Rep. 53-81, Wright-Patterson AFB (1952).

Dement, W. C., The basic function of dreaming. In T. M. Necomb (Ed.), *New Directions in Psychology II.* New York: Holt, Rinehart, & Winston, 238-246 (1966).

Felton, J. S., and Spencer, C., Morale of workers exposed to high levels of occupational noise. *Amer. Ind. Hyg. Ass. J.,* **22**, 136-147 (1961).

Fiske, D. W., Effects of monotonous and restricted stimulation. Ch. 5 in D. W. Fiske and S. R. Maddi (Eds.), *Functions of Varied Experience.* Homewood, Illinois: Dorsey Press (1961).

Fornwalt, N. E., Investigation into the effect of intermittent noise of constant periodicity vs. random periodicity on the performance of an industrial task. Master's thesis, Dept. Industr. Engr., Texas Technol. Coll. (1965).

Galloway, W., Objective limits for motor vehicle noise. Rep. No. 824, Van Nuys, California: Bolt, Beranek & Newman (1962).

Goodfriend, L. S., and Cardinell, R. L., *Noise in Hospitals.* Publ. Hlth. Publ. No. 930-D-11, Washington, D.C.: U.S. Govt. Print. Off. (1963).

Grandjean, E., *Biological Effects of Noise.* Zurich: Swiss Fed. Inst. Technol. Dept. Hyg. Work Physiol. (report undated).

Hoffman, H. S., and Fleshler, M., Startle reactions: Modification by background noise stimulation. *Science,* **141**, No. 3584, 928-930 (1963).

Jansen, G., Zur Enstehung vegetativer Funktionsstorungen durch Larmeinwirkung. *Arch. Gewehrpathol. Hyg.,* **17**, 238-261 (1959).

Jerison, H. J., and Wing, S., *Effects of Noise and Fatigue on a Complex Vigilance Task.* WADC Tech. Rep. TR-57-14, Wright Patterson AFB, (1957).

Kryter, K. D., Effects of noise on man. *J. Speech Hearing Dis.* Suppl. No. 1 (1950).

Kryter, K. D., Laboratory tests of physiological-psychological reactions to sonic booms. *J. acoust. Soc. Amer.,* **39**, Part 2, 565-572 (1966).

Kryter, K. D., Concepts of perceived noisiness, their implementation and application. *J. acoust. Soc. Amer.,* **43**, 344-361 (1968).

Kryter, K. D., and Pearsons, K. S., Some effects of spectral content and duration on perceived noise levels. *J. acoust. Soc. Amer.,* **35**, 866-883 (1963).

Mech, E. V., Performance on a verbal addition task related to experimental 'set' and verbal noise. *J. Exp. Educ.,* **22**, 1-17 (1953).

Michalova, C., and Hrubes, V., Frequency of neuroses and psychosomatic diseases mainly hypertension under the influence of noise (unpublished report).

Mills, C. H. G., and Robinson, D. W., The subjective rating of motor vehicle noise. *Engineer,* **211**, 1070-1074 (1961).

National Association of Home Builders Research Foundation, *Field Study of Residential Acoustics.* Rep. 155.09, Rockville, Maryland (1967).

National Safety Council, *Accident Facts.* Chicago (1967).

Nixon, C. W., Human responses to sonic boom. *Aerosp. Med.,* **36**, 399-405 (1965).

Nixon, C. W., Harris, C. S., and von Gierke, H. E., *Rail test to evaluate equilibrium in low-level wideband noise.* AMRL Tech. Rept. 66-85, Wright-Patterson Air Force Base, Ohio (1966).

Ostergaard, P. B., and Donley, R., *Preliminary Survey of Predicted Changes in Neigh-*

borhood Noise in West Orange, New Jersey, from a Proposed East-West Freeway. Cedar Knolls, N. J.: Goodfriend & Ostergaard Asso., Cedar Knolls Lab. (1963).

PARRACK, H. O., Community reaction to noise. Ch. 36 in C. M. Harris (Ed.), *Handbook of Noise Control.* New York: McGraw-Hill (1957).

PETERSON, A. P. G., and GROSS, E. E., *Handbook of Noise Measurement.* West Concord, Mass.: Gen. Radio Co., 61-65 (1967).

ROBINSON, D. W., Subjective scales and meter readings. *Control of Noise.* Symposium No. 12, Nat. Phys. Lab.. London: H. M. Stationery Office, 243-261 (1962).

STEIN, J., Music therapy treatment techniques. *Amer. J. Orthopsychiat.,* **33,** 521-528 (1963).

STEVENS, S. S., *The Effects of Noise and Vibration on Psychomotor Efficiency* Prelim. Rep. Psychoacoustics Lab., Harvard (1941).

TEICHNER, W. H., AREES, E., and REILLY, R., Noise and human performance, a psychophysiological approach. *Ergonomics,* **6,** 83-97 (1963).

THIESSEN, G. J., and OLSON, N., Community noise-surface transportation. *Sound Vibr.,* **2,** 10-16 (1968).

UHRBROCK, R. S., Music on the job, its influence on worker morale and production. *Personnel Psychol.,* **4,** 9-38 (1961).

WILBANKS, W. A., WEBB, W. B., and TOLHURST, G. C., *A Study of Intellectual Activity In a Noisy Environment.* Rep. No. 1, Sch. Aviat. Med., U. S. Nav. Air Sta., Pensacola, Florida (1956).

WILSON, A. H. (Chm.), *Noise.* Final Report of the Committee on the Problem of Noise. London: H. M. Stationery Office (1963).

WOKOUN, W., *Effect of Music on Work Performance.* Tech. Memo 1-68. U. S. Army Hum. Eng. Lab., Aberdeen Proving Ground, Maryland (1968).

WOODHEAD, M., Effects of brief loud noise on decision making. *J. acoust. Soc. Amer.,* **31,** 1329-1331 (1959).

WOODHEAD, M., The effect of bursts of noise on an arithmetic task. *Amer. Psychol.,* **77,** 627-633 (1964).

Effects of Noise on Physiological State

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Except for noise-induced hearing loss, we know of no extra-aural noise disease. Nevertheless, scientists and others dealing with noise problems are asked about the importance of noise for human health because of the great interest in these questions on the part of governments and people suffering from noise.

Does sound or noise hurt the human body? As several investigations have demonstrated, sounds or noises do change the physiological state. (Grandjean, 1960; Heinecker, 1959; and Maugeri). And since, in general, we consider extreme physiological changes to be a health hazard, we must think about sound or noise as being a potential health hazard. Until someone proves that these physiological changes are negligible, we must consider noise to have a possible detrimental influence on human health.

What kinds of noise influence the physiological state, and what are the effects? The answer to the first part of this question is that any noise may have such an influence—whether it is meaningful noise containing important information for the receiver or it is meaningless noise, with acoustical characteristics within certain intensities or frequency ranges. Two classifications of effects are stress reactions and vegetative reactions.

Meaningful noise can elicit stress reactions similar to those elicited by other stimuli, but man seems to become accustomed to most meaningful auditory stimuli if they are repeated frequently. One might wonder whether it is possible to give an exact limit beyond which human health is endangered by a meaningful noise. At this moment, scientific research is not yet able to give all criteria needed for setting such an exact limit. But these criteria must contain psychological and sociological, as well as physiological, parameters, for the results of interdisciplinary analysis indicate the importance of nonphysiological factors. In fact, it seems to me that nonphysiological factors are of greater relevance to such interdisciplinary studies than are purely physiological ones. Thus, cooperative work is greatly needed in the future.

Studies of Vegetative Reactions

Meaningless noise can elicit another kind of response, vegeative reaction. In our study a meaningless noise (white noise, 90 dB SPL) to which tested persons[1] were accustomed, effected changes in peripheral vegetative functions, such as the peripheral circulatory system and the pupillary function. Figure 1 shows the dilatation of the pupil occurred constantly during exposure to noise stimuli. By using a plethysmographic method (as photoelectrical, thermometrical, and fluvographical recordings), we found that blood volume in the skin was reduced, because of a vasoconstrictive effect. Figure 2 shows the original pulse amplitude recording, under quiet and noise conditions.

Calculating the stroke volume of the heart from sphygmographic and/or ballistographic recordings, we found a decrease of volume synchronized with the noise-induced vasoconstriction. Increase of diastolic blood pressure was often noted but disappeared sometimes after repeated testing over a period of several months.

The next step was to test the possibility of heightening the above-mentioned vegetative reactions by delivering repeated noise bursts with distinct sound characteristics. It was possible to record noise-induced vasoconstrictive effects of repeated noise bursts (90 dB SPL) at exposures ranging from 300 msec to 90 min. We noticed cumulative vegetative reactions when using repeated noise bursts of 0.5 min duration at intervals of 1.5-3.0 min over a total exposure time

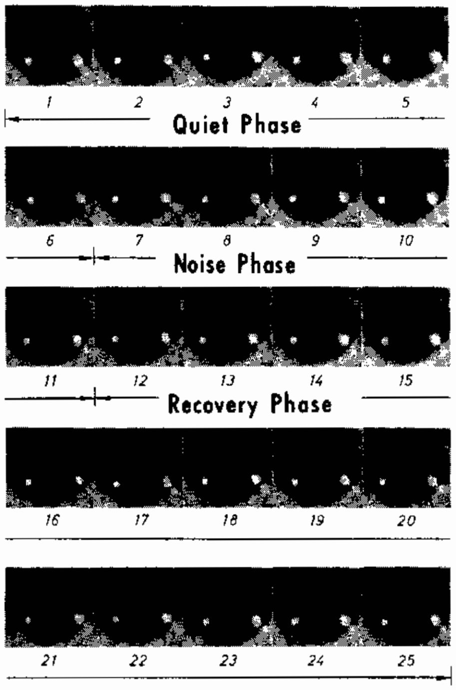

FIGURE 1. Original photographic recordings of the pupil. Nr 1-6: under quiet conditions. Nr 7-11: under noise. Nr 12-25: quiet after-period. Pictures were taken at 5-sec intervals.

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[1] Most subjects were students of education, with an age range of 20 to 28 years. They participated repeatedly in noise experiments over a period of three years. The experiments involved daily sessions of 30 to 60 min each. During this three-year period, physiological reactions appeared to be constant in each experiment.

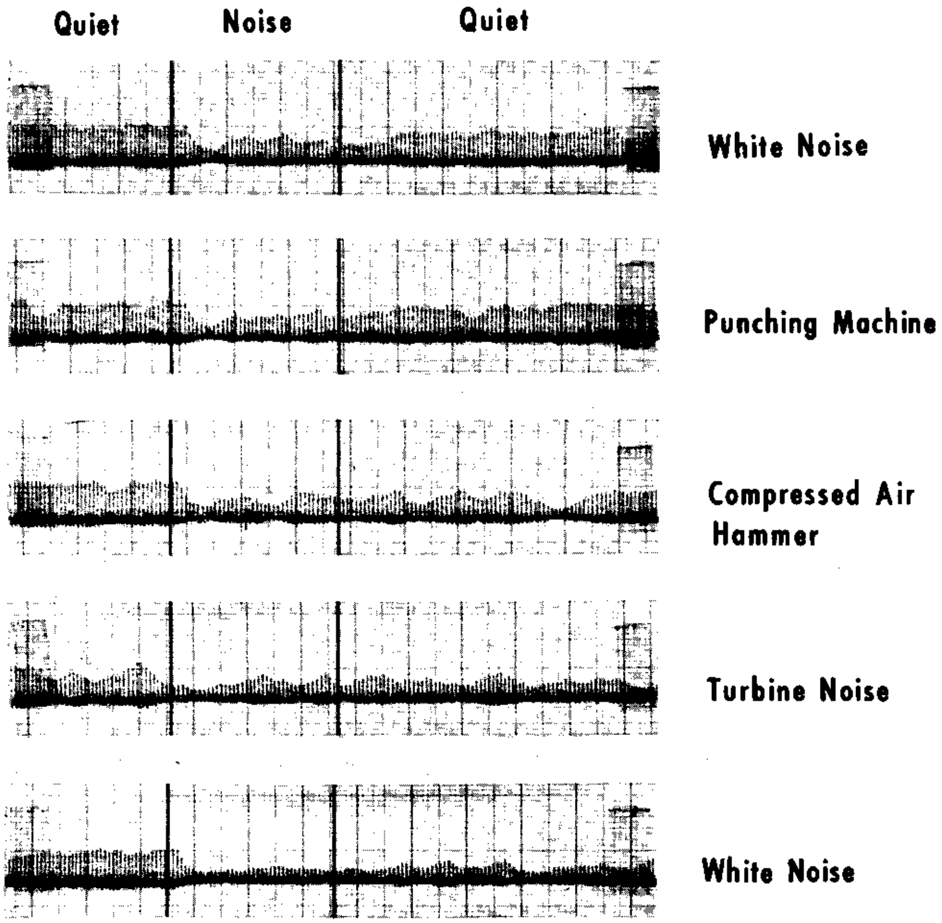

FIGURE 2. Original pulse amplitude recording. Before the marker-line: quiet conditions. Behind the first marker-line: white noise 95 dB. Behind the second marker-line: quiet after-period. First line: white noise. Second line: punching machine. Third line: air pressure hammer. Fourth line: turbo engine. Fifth line: white noise.

of half an hour. Figure 3 shows the cumulative effects observed. The vasoconstrictive effect was present during the entire time of stimulation. Figure 4 demonstrates pulse amplitude differences of seven subjects during repeated testing under quiet and noise conditions.

Does the degree of vegetative reaction depend upon certain acoustical characteristics? Our tests showed that vasoconstrictive effects, as well as pupil dilatation (Figure 5), depend upon intensity and bandwidth; beginning at 70 dB SPL (white noise), vasoconstriction and dilatation both increased with increasing sound intensity. Figures 6-8 show how increasing SPL affected pulse amplitude and pupil size. The greater the bandwidth, the greater the vasoconstrictive effects with constant intensity level. These reactions were independent of feelings of annoyance, or of any other emotion of the subjects.

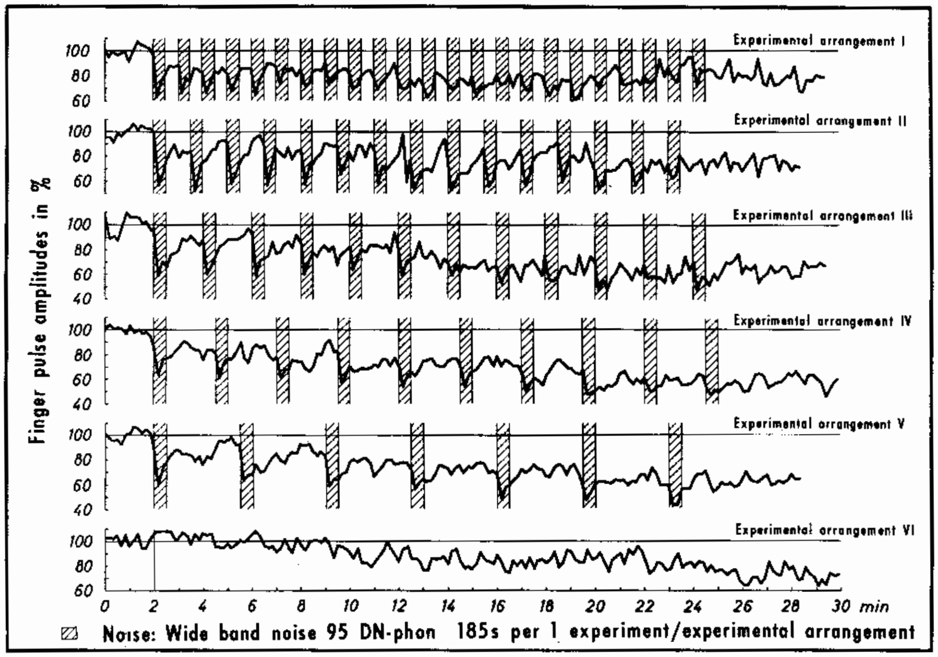

FIGURE 3. Cumulative effects of noise. The marked periods indicate 0.5 min of noise exposure with rest periods. First line: 0.5 min Second line: 1.0 min Third line: 1.5 min Fourth line: 2.0 Fifth line: 3.0 min Sixth line: no noise. The finger pulse amplitudes at the left are given in percentage of the preceding quiet period. Each line represents the means of 18 subjects.

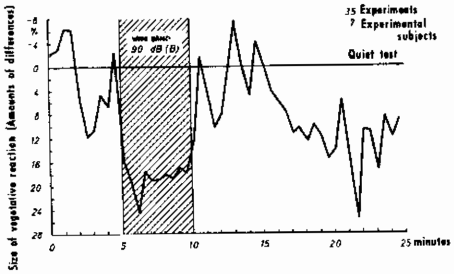

FIGURE 4. Differences of pulse amplitudes of 7 subjects between 35 quiet tests (line 0) and 35 noise tests (90 dB, 5 min noise exposure.)

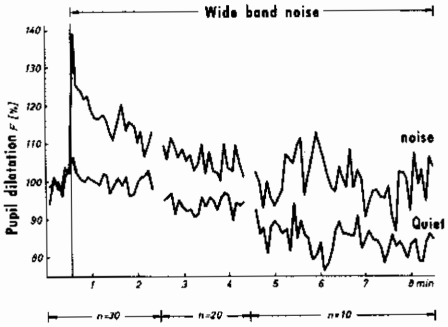

FIGURE 5. Changes in pupil size (in percentage of a preceding quiet period). Upper line: under noise conditions—95 dB. Lower line: without noise—55 dB.

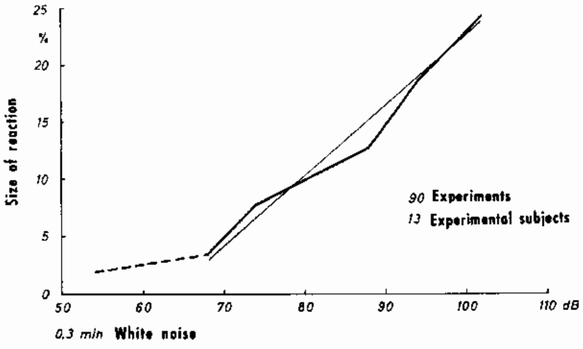

FIGURE 6. Relation of vegetative reaction (decrease of pulse amplitudes in percentage) to sound-pressure level (white noise).

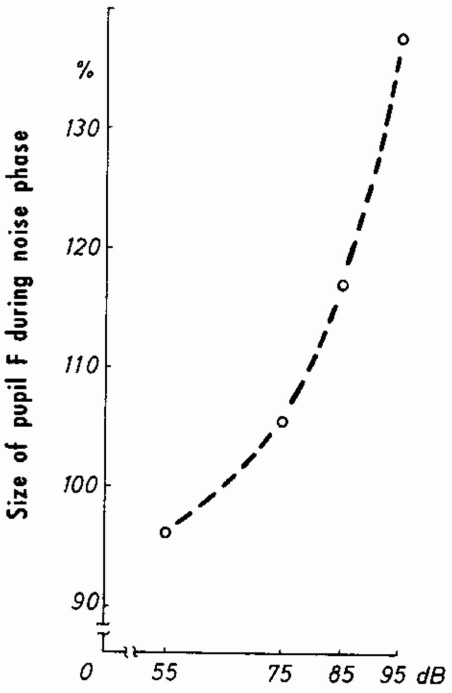

FIGURE 7. Relation of pupil size (in percentage) to sound-pressure level (white noise).

The reactions caused by meaningless noise up to 95 dB must not necessarily be regarded as producing pathological side effects when noise is applied once or only a few times. They might, however, cause pathological side effects when exposure occurs over long years to intensities of more than 95 dB. Investigations with industrial workers in high noise surroundings have confirmed such hazards (Jansen, 1959). If there is an additional psychic or somatic stress, human health might be endangered even by lower intensities and shorter exposure times.

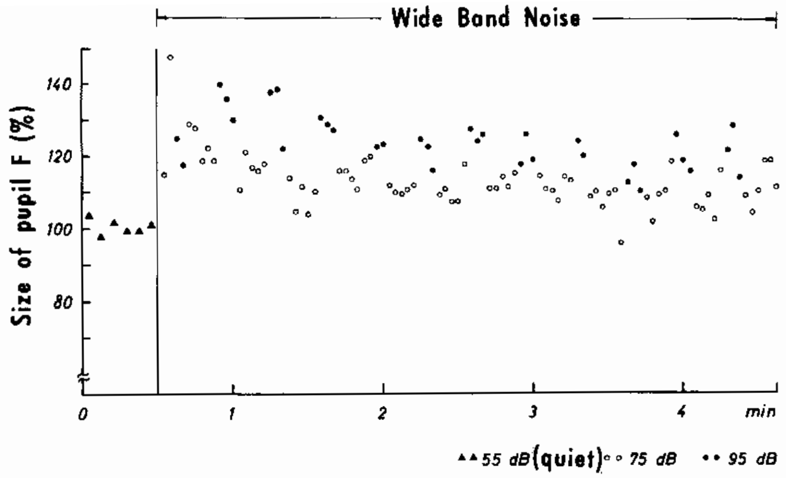

FIGURE 8. Changes in pupil size with continuous intermittent noise of 75 dB and 30-sec exposure (circles), and of 95 dB and 20-sec exposure (black points). Eight subjects, 12 tests each.

One question of particular interest in our study was whether or not noise interferred with sleep. We found that noise of modest intensities (from 55-60 dB and more) did influence the deepest stage of sleep in our subjects, when they were exposed during sleep to noise stimuli lasting from 300 msec to 90 min (Figures 9 through 11).

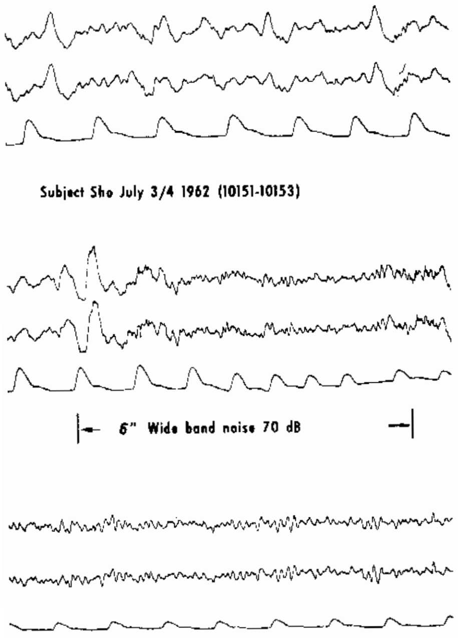

FIGURE 9. E5G and pulse amplitude during sleep with 70 dB white noise stimulus (6 sec).

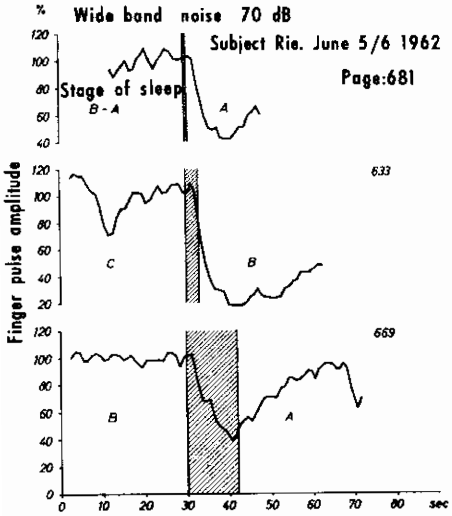

FIGURE 10. Finger pulse amplitudes during sleep. Upper line: noise bursts of 300 msec. Middle line: 3 sec. Lower line: 12 sec.

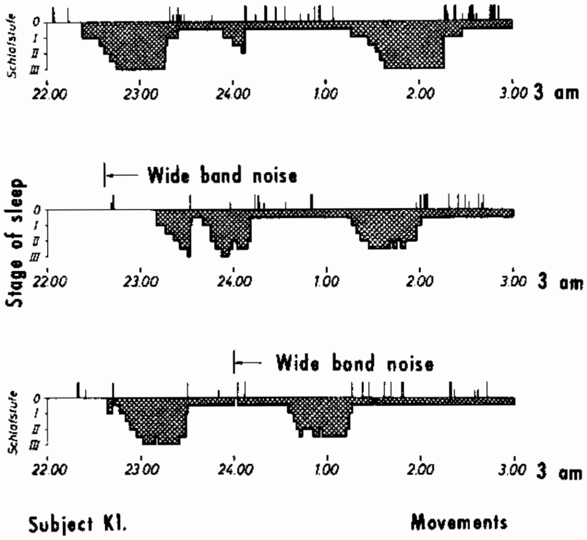

FIGURE 11. Stages of sleep (EEG) on three different nights. Upper graph: without noise. Middle graph 70 dB white noise for 90-min stimulation with start of testing. Lower graph the same noise stimulus given from midnight until 1:30 a.m. Ordinate: O—awake, I—dozing, II—medium sleep, III—deep sleep. White noise of 70 dB, for example, changed the characteristic frequency of the EEG of a man in deep sleep from 2-4 Hz to 8-12 Hz though he was not awakened by the stimuli.

Although seven persons were examined during more than 120 nights, we were unable to establish the existence of a "sleep interference intensity," or SII. In addition to the acoustical stimuli given during sleep, what we have earlier called "meaningful noise" (as a crying baby, or noise from a landing jet) was responsible for amplifying the physiological effects.

Establishing Risk Criteria

Is it possible to establish a limit for normal physiological reactions to noise? Scientific noise research in extra-aural fields has indicated what seems to be a risk criterion. When recording the vegetative reactions (pulse amplitudes) from 60, 70, . . . 110 dB in all third-octave bands from 200 Hz to 8000 Hz, we found that the reactions increased with intensity (Figure 12). There was no further increase in reactions at intensities above 3000 Hz.

By calculating the results of these experiments, a regression equation was developed which makes it possible to predict the degree of vegetative reaction by different intensities and bandwidths. Moreover, the formula shows a critical value of 94 dB at 1 kHz with a decline of 1 dB/octave.

$$R = (+1.19 \times 10^{-3} \times p^{3} - 3.42 \times 10^{-1} \times p^{2} + 3.28 \times 10^{1} \times p - 1.04 \times 10^{3}) + (+6.82 \times 10^{-7} \times p^{3} - 1.86 \times 10^{-4} \times p^{2} + 1.70 \times 10^{-2} \times p - 5.08 \times 10^{-1}) \times f$$

for $f = 1000$ Hz

$$R = (1.19 \times 10^{-3} \times p^{3} - 3.42 \times 10^{-1} \times p^{2} + 3.28 \times 10 \times p - 1.04 \times 10^{3}) + 1000 \times (6.82 \times 10^{-7} \times p^{3} - 1.86 \times 10^{-4} \times p^{2} + 1.70 \times 10^{-2} \times p - 5.08 \times 10^{-1})$$

$$R' = \frac{dR}{dp} = 3 \times 1.87 \times p^{2} - 2 \times 0.53 \times p + 49.80$$

Point of inflection: $R' = 0$

$$\begin{aligned} &5.61 \times 10^{-3} \times p^{2} - 1.06 \times p + 49.80 = 0 \\ &p^{2} - 1.88 \times 10^{2} \times p + 88.83 \times 10^{2} = 0 \\ &p_{1,2} = +94.18 \pm 88.69 \times 10^{2} - 88.82 \times 10^{2} \end{aligned}$$

$$R'' = \frac{d^{2}R}{dp^{2}} = 2 \times 3 \times 1.87 \times 10^{-3} \times p - 2 \times 0.53$$

$$\begin{aligned} R'' = \quad & 11.21 \times 10^{-3} \times p - 1.06 \\ & 11.21 \times 10^{-3} \times p = +1.06 \\ & p = +94.18 \end{aligned}$$

$$R''' \neq 0$$

Based on this scientific extra-aural criterion (Figure 13), we propose to limit noise intensities to 95 dB (small bandwidth) or 88 dB (wide-band noise) during any noise exposure.

Is there a connection between noise-induced vegetative reaction, motor skill, and annoyance created by a meaningless noise? Our first results have demon-

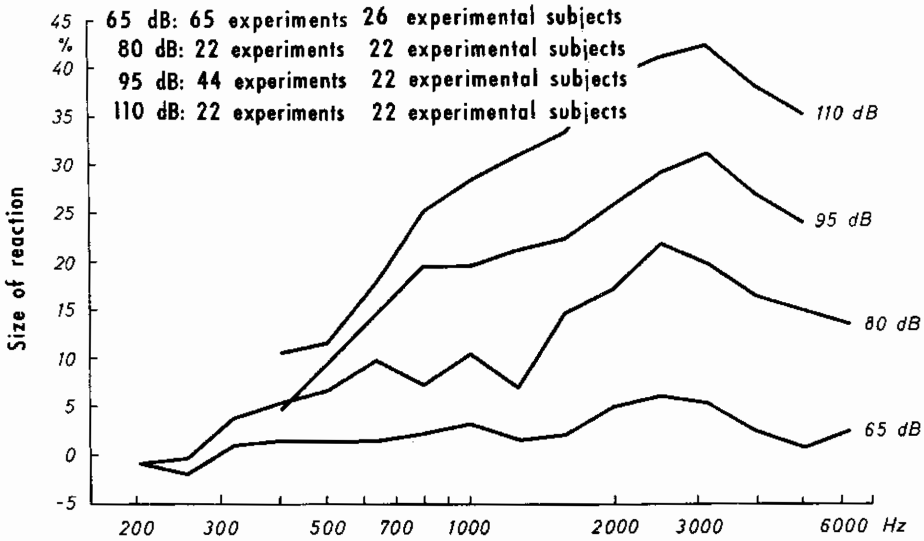

FIGURE 12. Vegetative reaction (decrease of pulse amplitudes in percentage) in relation to third-octave bands with four different intensities.

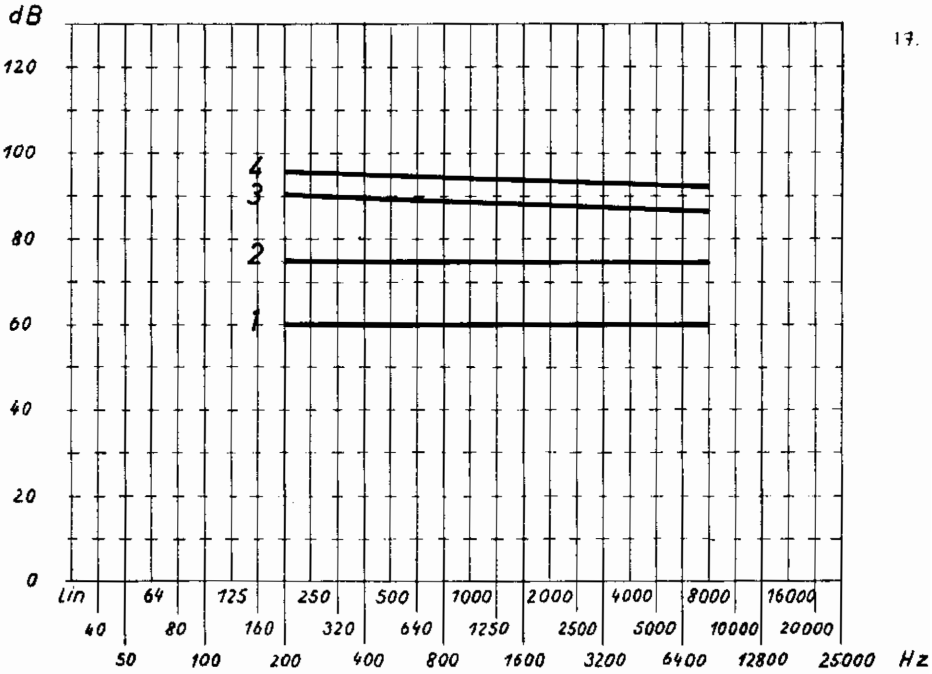

FIGURE 13. Proposed risk criteria: (1) Possible vegetative reaction of usual range, (2) pronounced vegetative reaction, (3) possible danger-zone for wide-band noise. (4) Beginning of injury?

strated that there must be a connection between these factors. (Jansen and Hoffmann, 1965; Jansen, 1967). Testing vegetative reactions seems to indicate interindividual differences in the degree of disturbance. That is, personality dimensions influence reaction to noise. Examination of handwriting pressure and emotional factors (annoyance, activity, tension, nervousness) shows that subjects high in neuroticism suffer more under noise, by being annoyed and showing distractions in motor coordination, than do subjects less neurotic in the general vegetative lability of their nervous systems. We noted that meaningless noise changed motor coordination and emotional factors only at intensities higher than 75 dB. Further studies of this problem of individual differences (the influence of personality dimensions on reactions to noise) are in the process of being investigated.

Bibliography

Grandjean, E., Physiologische und psychologische Wirkungen des Laerms. Mensch und Umwelt, *Documenta Geigy* **4**, 13-42 (1960).

Heinecker, R., Individuelle Unterschiede in der Reaktion von Kreislauf und Gasstoffwechsel auf dosierte Belastungen: Cold Pressur Test, Flackerlicht, Laerm, korperliche Arbeit. *Arch. Kreislaufforsch.*, **30**, 1 (1959).

Maugeri, S., Effeti biologici del rumore industriale. Forsch.-Ber. 350 der EGKS, Hohe Behorde, Luxemburg. Patologia da Rumore. *Il Progresso Medico*, **13**, 423-429.

Jansen, G., Zur Entstehung vegetativer Funktionsstoerungen durch Laermeinwirkung. *Arch. Gewerbepath* **17**, 238-261 (1959).

Jansen, G., and Hoffmann, H., Laermbedingte Aenderungen der Feinmotorik und Laestigkeitsempfindungen in Abhaengigkeit von bestimmten Persoenlichkeitsdimensionen. *Z. exper. angew. Psychol.*, **12**, 594-613 (1965).

Jansen, G., Zur nervoesen Belastung durch Laerm. *Beih. Zbl. Arbeitsmed. Arbeitsschutz*, **9** (1967).

Summary

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The Biological Background of Noise Effects

The physiological organization of the auditory pathways in the brain has two distinct systems: a direct pathway called the specific auditory system; and the unspecific pathway, branching off from the specific one in the activating system of the reticular formation in the brain stem (Figure 1).

In the internal ear, noise can affect the specific auditory system and cause temporary and permanent threshold shift. This is an important occupational health problem.

The direct pathway ends in the auditory cortex where the sum of arriving nerve impulses is consciously integrated, perceived and interpreted. Noise can affect this system by masking wanted speech information (speech interference).

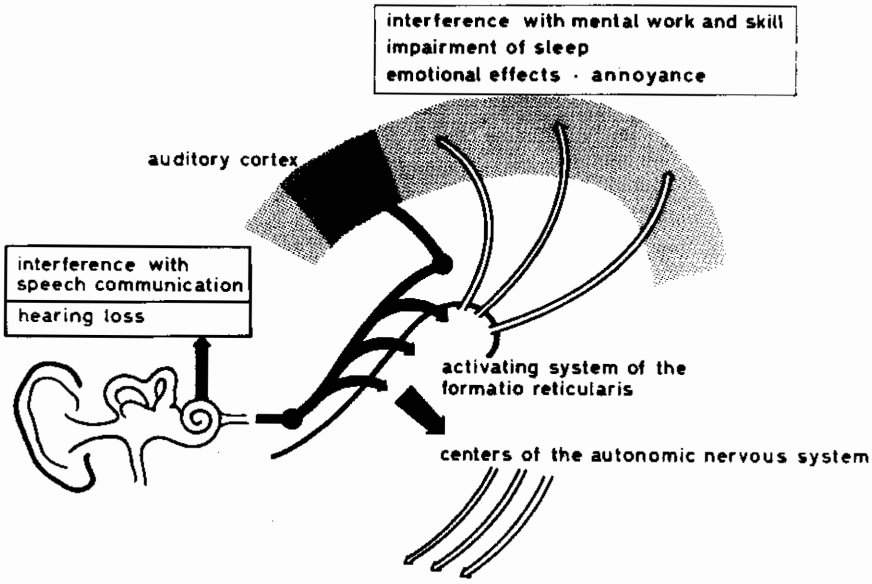

FIGURE 1. The physiological organization of the auditory pathways in the brain, and their relation to the effects of noise on man.

The unspecific pathway--or the nonauditory system—has a key position in generating all of the side effects of noise in the reticular formation. Auditory stimuli reaching the reticular formation will generate new stimuli spreading out into the entire cortex creating thereby an arousal or a generalized alerting response.

The biological sense of this system is to arouse an animal or a human being in order to enable him to focus attention on external acoustical information that might have the significance of a life danger.

At the same time, the activating system also spreads the stimulus to the centers of the autonomic nervous system, which stimulates internal organs such as the heart, peripheral circulation, and digestive tube.

Therefore, the activating system is somehow a central alerting system which enables the whole organism to react in an adequate way to a given external situation. While noise is certainly one of the most important sensory inputs to this alerting system, it is also stimulated by any other sensory system and by emotions.

Cohen reported that laboratory experiments concerning the effect of noise on human performance produced contradictory or, in some cases, no results.

This can be partly explained if we realize that in many test situations the subjects are stimulated through the activating system by the test itself so that an additional noise stimulus will rarely show further effects. From this point of view laboratory tests are often not a good simulation, or model, for daily working conditions.

Cohen reported that tasks requiring continual attention are frequently impaired by noise. In these cases, it is obviously the distraction effect—the deviation of attention by an arousal—which interferes with mental concentration. It is well known that intellectual people, engaged in creative mental work, are especially sensitive to noise and feel noise is an annoying intruder.

Noise as a Public Health Problem

There is full agreement in considering hearing loss a serious health injury, but there is less agreement about the evaluation of the importance of all other effects of noise as a health hazard.

In Europe, many experts approach this problem from the definition of health given by the World Health Organization: "Health is a state of complete physical, mental and social well-being." It is, therefore, logical to consider noise a health hazard when it interferes in a significant way with sleep or rest, when it is annoying or disturbing (including cases of speech interference), or when it produces such emotional effects as fear.

The great difficulty is the distinction between tolerable and intolerable noise and between justified and unjustified complaints.

In this connection, I will cite another important psychophysiological regulating and protecting process: The habituation to noise.

We know that the habituation process is due to a feedback system from the cortex to the activating system, which is able to selectively extinguish some noise stimuli which prove to be irrelevant. This is why animals, or human beings, have the ability to sleep peacefully in the presence of many potentially alerting noise stimuli. It explains also why a mother can ignore all sorts of noise but is awakened by any small noise of her child; through habituation she learned to distinguish between irreltvant traffic noise and the significant sound manifestation of her child. The process of habituation prevents human beings and animals from reacting indistinctly and every time to any kind of noise. The reticular formation therefore has the role of a discriminative input filter.

The comparison between the two surveys (in London 1948 and 1967) reveals that the complaints about external noise increased from 1948 to 1961. This result is certainly not conclusive, but it indicates there is no evidence for a habituation process against external traffic noise.

We know well the existence and the mechanism of the habituation process, but we unfortunately know very little about this protecting mechanism in every-day life, and especially against the increasing noise of our modern environment. More research in this field would be of great practical importance.

If we look from the point of view of public health to present knowledge on noise effects, we see we have good information to evaluate the risk of hearing losses and the risk of speech interference. But we have much less information on the importance of nonauditory effects for the state of well-being and health of modern man.

In Switzerland, a group of experts worked out recommendations for noise limits in order to give to the authorities some base for community planning, for police regulations and for court judgments (see Table 1).

This group of experts was aware of a large gap between scientific knowledge and the possible recommendations they could give. After long discussion the opinion was accepted, that the authorities responsible for public health could

TABLE 1. Recommended noise limits in Switzerland.

	Background Noise		*Frequent Peaks*		*Rare Peaks*	
Area	*Night dB(A)*	*Day dB(A)*	*Night dB(A)*	*Day dB(A)*	*Night dB(A)*	*Day dB(A)*
Health resort	35	45	45	50	55	55
Quiet residential	45	55	55	65	65	70
Mixed	45	60	55	70	65	75
Commercial	50	60	60	70	65	75
Industrial	55	65	60	75	70	80
Traffic arteries	60	70	70	80	80	90

Measurement with microphone at open window recommended.
Desirable values 10 dB less, but not more than 30 dB less.
Background noise: mean value (average noise value without peaks).
Frequent peaks: 7–60 peaks per hr.
Rare peaks: 1–6 peaks per hr.

not wait much longer for more scientific information and that the urgency of protective measures required provisional recommendations.

Clearly, it would be wise to increase our research efforts (especially on the noise effects in large communities) in order to reduce as much as possible the gap between scientific knowledge and public health practice so that human beings may be protected from environmental noise loads in an adequate manner.

Panel II

Industrial Noise and the Worker

Opening Remarks

Aram Glorig, Panel Chairman

Callier Hearing and Speech Center, Dallas, Texas

There are many sources of noise in our highly complex civilization. In fact, it is almost impossible to find a large group of individuals who have not been exposed at one time or another to noise of one magnitude or another.

The noise source most common to man is industrial and large population studies indicate that this is by far the most important single cause of hearing loss. If two populations are considered, one the general population and the other an industrially exposed population, the difference in amount of hearing loss is between 10 and 30% for all ages. At age 55, 22% of the individuals in a non-noise-exposed population show significant hearing impairment; in an industrial group the percentage is 46%.

Although mankind has been associated throughout its history with sound of one kind or another, it was not until relatively recently that examples of the adverse organic effects of sound (noise) have been recorded. This fact is understandable since, although isolated examples of noises existed, the widespread noise exposure that accompanied the onset and development of modern industry has been present only during recent times. As mass production increased and heavy mechanization progressed, the problem of exposure to noise also increased. In spite of this, no recognition of the effects of noise on man was recorded until about 1831 when Fosbroke of England recorded hearing loss in blacksmiths. Some 30 years later, E. H. Weber made the first report of hearing loss in boilermakers and railroad men.

The medical history of noise-induced hearing loss is fairly clear-cut, and there is no doubt that hearing loss will result from noise exposure; but legally the problem is much more complex. Terms such as *disability* and *occupational disease,* when used in the legal sense, have meanings entirely different from their medical meanings. For example, the term *disability* used in the medical sense indicates a dysfunction of some particular organ or physiological process of the human body; within a legal framework, loss of function or injury to the human body becomes a disability only if defined as such by law. This is true of the term *occupational disease,* also. We may be correct in saying that a loss of function is occupationally induced, but legally that loss of function might not be an occupational disease. What may be classed as an occupational disease or a disability in one state will not necessarily be so classed in another.

As life has progressed from the rural community and an isolated family hierarchy to the urban community where occupation is centralized, the question of responsibility for occupationally connected bodily injury has become increasingly important. In the early history of the Industrial Revolution, when a workman was injured on the job his only recourse was through common law. He could sue in the common law courts only on the basis of negligence. If it was established that the employer had been negligent, the employee collected compensation. The significance of this problem is well put by Joseph A. Sullivan, legal advisor to Liberty Mutual Insurance Company, in the following words:

> Prior to the passage of compensation laws, if an injured worker sued his employer, he would have to have proved that the injury was due to the negligence of the employer in order to recover damages. In addition, the employer had three potent common law defenses: contributory negligence, assumption of risk, and negligence of fellow servants. Many injured workers went uncompensated and the burden of their maintenance, during long weeks of convalescence from injury, fell upon local welfare and charity agencies. It became apparent that the results were too harsh against the claims of injured workers. (Larson, *The Law of Workmen's Compensation.* Vol. 1, Sec. 4.30 and 4.50, 1966.)

It is clear that with such a system there would be many obstacles to payment of compensation for occupationally induced bodily injury. Naturally, this system resulted in interminable haggling between employer and employee and, consequently, a system of statutes evolved which allowed the employee and the employer to settle these problems on the basis of fixed definitions and rates. These statutes became known as "Workmen's Compensation Laws." The new system suffered a great many growing pains, and many of the problems of workmen's compensation still are not settled. The significance of the compensation system was well summarized by the Supreme Court of the State of Washington as early as 1916. The Court said this:

> Present laws came of a great compromise between employers and employed. Both had suffered under the old system, the employers by heavy judgments of which half was imposing lawyer's booty; the workmen through the old defense of exhaustion in wasteful litigation. Both wanted peace. The master, in exchange for limited liability, was willing to pay on some claims in the future where in the past there had been no liability at all. The servant was willing not only to give up trial by jury, but to accept far less than he had often won in court, provided he was sure to get the small sum without having to fight for it. (*Stertz* v. *Industrial Insurance Commission*, 91 Washington 588, p. 590.)

Present-day concepts have led to considerable confusion as to the original intent of the workmen's compensation laws. At the start, no one had defined the purpose of workmen's compensation specifically as payment for loss of wages. Through legal interpretations, however, the principle of "wage loss" became an unwritten precept. Compensation was not made for bodily injury nor for damages but to replace loss of earning capacity. Earlier, when suits had been filed against an employer on the basis of common law, there was no intent to compensate for loss of wages, but to settle for bodily damage with a nonspecified sum, the amount of which was unpredictable. After workmen's compensation laws were passed, the employee was compensated with small, specified payments that provided a means of supplementing his reduced earnings. No attempt was made to evaluate the worth of the member that had suffered injury and, although the employee frequently received less than if he had won against the employer in the common law courts, he was more certain to receive compensation by written law. It became not a question of whether the man was eligible for compensation but a question of establishing the significance of the injury to his occupation. If the injury was considered to be occupationally induced, the employee received compensation on the basis of a schedule related to the specific injury. The early compensation laws provided only for occupationally related *injuries,* as distinguished from diseases. By common agreement, there had to have been a specific date of injury and the injury must have produced a wage loss.

As industrialization progressed and more workmen were employed, it became evident that many industrial processes directly produced specific diseases in workers. Such conditions could not be defined as injuries. They did not have a specific date of injury, nor in many cases did they produce a wage loss. As it became more obvious that such conditions were directly caused by occupation, the employer and the insurance carrier alike foresaw many obstacles to the workmen's compensation system. Unlike injuries, occupational diseases could not be predicted from previous records nor, in many instances, was there any apparent means of prevention. On the one hand, occupational disease was thought of as a natural result of the industry; this was part of the risk the man took when he chose to work in this particular type of job. On the other hand, injuries were not peculiar to any one industry. They were thought by employer and employee alike to be a result of fault on someone's part. Whereas, in most cases occupational disease is insidious and occurs over a prolonged period, injury is instantaneous and can be evaluated more readily in terms of disability and liability. However, who is liable and how much liability should be attributed to each employer over the prolonged onset and course of an occupational disease has posed many difficult problems. The matter of accrued liability with reserves for payments became a serious problem because there was no way of knowing how many employees would contract the diseases. Thus, many of the laws made provision only for specific diseases and frequently diseases which might be occupationally induced were not considered compensable. Some states limited the accrued liability by providing that any employee in whom a pre-existing condition could be proved was exempt from compensation benefits.

Most of the recent problems encountered in establishing equitable compensation laws result from attempts to provide compensation for occupational disease. Noise-induced hearing loss is a good example of this. It is unquestioned that hearing loss reduces a man's capacity to live a normal life and, in specific instances, may reduce his earning capacity; but if the legal criteria used in many states for establishing disability are applied to noise-induced hearing loss, it is not a disability. There is no date of injury nor, in most cases, is there a loss of wages.

As more compensation claims were adjudicated, certain provisions of the laws began to assume different meanings through various and more inclusive interpretations by judges, courts, and compensation commissioners. As time passed and the problem of compensation in general became more important, there was a tendency to broaden the coverage of the statutes. A good example of this trend is found in the interpretation of the law covering noise-induced hearing loss cases. In 1948 the State of New York, in *Slawinski* v. *J. H. Williams & Co.* (273 App. Div. 826, N.Y. 546, 81 N.E. [2nd] 93), declared that noise-induced hearing loss was an occupational disease and involved compensation. This case proceeded through several courts, and the final decision was rendered by the U.S. Supreme Court in favor of the claimant, awarding compensation on the basis of existing laws. The decision was clearly an interpretation of intent rather than an actual expression of the content of the law. The law at that time stated that there must be a date of injury and a loss of wages before an occupational disease could be considered a disability.

The problem was further aggravated by a case in Wisconsin filed in 1951. Again, the question of disability was at stake. At that time Wisconsin law defined disability due to occupational disease on the basis of the scheduled injury law, which stated that there must be a date of injury and a wage loss. The date of injury was defined as the date of the last day of work for the last employer whose employment had caused the disability (Wisconsin Workmen's Compensation Act, Section 102.01 [2].) The claimant in the Wisconsin case, however, had not lost time at work prior to filing the claim (nor had he lost any since) and one court contended that there could, therefore, be no date of injury. This case progressed through the courts and the original decision handed down by the Commission was upheld by the Wisconsin Supreme Court (*Green Bay Drop Forge Co.* v. *Wisconsin Industrial Commission.* 265, Wis. 38, 60, N.W. [2nd] 409). Needless to say, both labor and industry realized that as a result of this decision Wisconsin industry faced a serious problem. How the problem was solved in Wisconsin need not be discussed here. Suffice it to say that a new law written expressly for noise-induced hearing loss was passed and became effective in July of 1955. The law reflects the benefits derived from cooperation between labor, management, and medicine. In my opinion, it is the most advanced law in the country today. The Wisconsin amendment to the occupational disease law has been called a law that both labor and industry can live with.

A discussion of the legal aspects of disability would be incomplete without mention of the "compensation for wage loss" concept; the original intent of compensation laws. From the inception of workmen's compensation laws in the decade between 1910 and 1920 until the New York case in 1948 there had been no departures from the wage loss concept. However, when Slawinski received compensation with no date of injury and no wage loss, it was evident that the wage loss concept was in for considerable re-examination. Then when the state of Wisconsin decided in favor of a claimant under similar conditions, loss of wages as a basis for establishing compensation received a serious setback. Heretofore, this concept had acted as a brake which could be depended upon to limit compensation within reasonable bounds. With these interpretations, however, it appeared that industry was in danger of serious financial embarrassment were the wage loss concept completely abandoned.

It is not our prerogative as professionals to try to contrast disability, defined on the basis of date of injury and loss of earnings, with social disability, based upon a man's relation to his total life. Much of what we might say would be biased. As professionals, it is our duty to preserve man's various functions and restore them whenever possible. As professionals, we cannot and should not relate loss of function to dollars and cents. We must evaluate loss of function by its effect on the total man. On the other hand, we are members of the community and are, in this capacity, concerned with loss of function as it affects the community. What the community can afford to pay for loss of bodily function and whether payment shall be based upon man's relation to his industrial life or to his total life must be regulated by community opinion. As members of the community, we might argue that compensation benefits must be based upon the opinions of the whole community, not only the industrial community. After all, the employee is a member of the industrial community for only a relatively small part of his lifetime, but he remains a part of the total community for his entire life. As professionals, we must urge that the industrial community do everything possible to preserve human functions. We should be impartial in our decisions regarding all members of the industrial community, employee and employer alike. Our concern is conservation, not compensation. Much of what we do will influence the application of compensation laws to employer and employee, but whether the laws are based on wage loss or social loss must be decided upon by the total community.

References

FOSBROKE, J., Practical observations on the pathology and treatment of deafness, No. II. *Lancet*, **19**, 645-648 (1831).

Acceptable Noise Exposures—Damage Risk Criteria

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There is a long, complex history to the efforts that have been made to relate exposure to noise with loss of hearing in ways that would allow us to specify "acceptable noise exposures." We plan to pass lightly over this history by referring to just a few key decisions by the medical community regarding definitions of *damage* or *impairment*.

On the positive side of the ledger, we now have some reasonable and workable approximations concerning safe and hazardous exposures to steady-state noise. Our answers are based on a few simple postulates and on the carefully measured relations for temporary threshold shifts described earlier by Ward. *Equinoxious* (equally harmful) contours detailing the limits of acceptable exposure to noise have been published. Simplified versions, appropriate to many common noise exposures, are also available. Here we will outline the general nature of these contours.

On the negative side, we want to give about equal time to some unanswered questions about several assumptions that had to be made in order to reach these workable approximations. Some of these questions relate to the simple postulates cited above; others relate to the problems of defining *damage* and *risk*.

Ward has already shown that temporary and permanent shifts of auditory thresholds for pure tones depend on the level, the effective duration, and the frequency spectrum of the noise; on the rest periods away from the noise; and on the years of repeated exposure to noise. There are two important concepts we can identify here. The first is that threshold shift will be a measure of damage. The second is that the single dimension of noise level will not be enough to determine acceptability. The substitution of "acceptable noise exposures" for "acceptable noise levels" in the title of our report reflects this very important distinction. An exposure to noise may be described in terms of various combinations of the dimensions listed above. An acceptable noise exposure, then, is one for which there is a known, safe set of values for the level, effective duration, and frequency spectrum; for rest periods; and for years of exposure. A hazardous noise exposure is one that produces some injury. But before continuing we need to define *damage* and *risk* so that we can then define *safe* and *hazardous.*

Damage Risk Criteria

There are social and legal considerations as important to the definition of *damage* as the medical considerations. We could define *damage* in terms of injury to the cells and tissues of the inner ear, but these are not available for direct inspection during life. There is more medico-legal precedent for measuring or evaluating damage in terms of impairment of a function. Of course, there are many aspects to the function of hearing. There is the ability to hear speech, to hear music, to hear faint sounds, to hear significant sounds in noisy places, and so on. The choice of those abilities to be protected when we set standards for evaluating impairment is largely an arbitrary social decision. The medical community has produced two statements that represent a fair, present consensus oriented toward their medical responsibilities for determining impairment of hearing in a legal sense.

The first statement was very general and dealt with the principles for evaluating hearing loss (*Principles for Evaluating Hearing Loss, 1955*). It proposed that hearing for everyday speech was the key function to be evaluated in determining the degree of hearing impairment, but did not propose a specific method for this evaluation. The second statement (*Guide to the Evaluation of Permanent Impairment, 1961*) was more specific. It recommended that, for lack of an adequately standardized test for everyday speech, the average hearing level for the pure tones 500 Hz, 1000 Hz, and 2000 Hz be used as an indirect measure of the probable ability to hear speech. Figure 1 shows the relation of the average hearing level for these three frequencies to the range of normal hearing and to the range of impaired hearing. The onset of disability or impairment is at an average hearing level of 26 dB ISO 1964 (15 dB ASA 1951) and total impairment is at 93 dB ISO 1964 (82 dB ASA 1951). To a great degree, the lower boundary for impairment represents inferences from the clinical experience that persons with average hearing levels less than 26 dB ISO 1964 rarely seek professional help because of impaired hearing. A hearing aid is commonly needed for everyday speech when impairment has reached 22.5% at 41 dB hearing level.

Another concept that grows out of the medico-legal orientation toward injury by noise is that of noise-induced permanent threshold shift (NIPTS). The employer with a noisy factory is considered to be responsible only for that part of a threshold shift produced by noise and should not be liable for the threshold shifts that commonly occur with age even in the absence of exposure to injurious noises. NIPTS, then, is measured statistically and damage is inferred from these measures.

A comparable, meaningful consensus on an operational definition of *risk* has not yet been achieved. Half of a population will have a hearing level equal to or worse than that population's median hearing level. If we choose a noise exposure that will produce a median hearing level equal to that for the onset of impairment, then about half the noise-exposed population will have some impairment. On the face of it this is a poor way to achieve safety. In practice, two strategies have been adopted to avoid this problem. The first is to set a hearing-level criterion which is better than hearing measured at the onset of impairment. This would provide some margin for safety, making the limit of

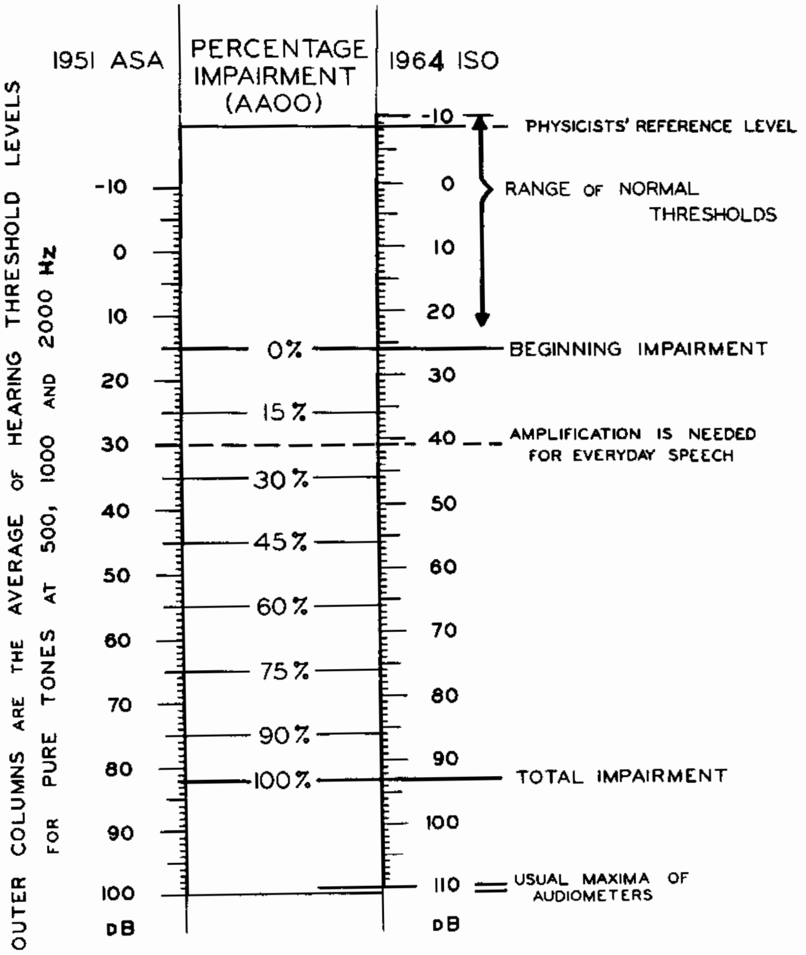

FIGURE 1. Average Hearing Levels and Hearing Impairment (From H. Davis and F. W. Kranz, "The International Standard Reference Zero for Pure-Tone Audiometers and its Relation to the Evaluation of Impairment of Hearing," *J. Speech Hearing Res.*, 7, 7-16, 1964.) The center column represents percentage impairment of hearing calculated according to the "three-frequency" average. The hearing levels in the column "1964 ISO" correspond to the audiometric scale published by the International Organization for Standards in 1964. The hearing levels in the column "1951 ASA" are the equivalent levels that correspond to the audiometric scale in the American Standard for Audiometers for General Diagnostic Purposes, Z24.5-1951.

acceptable exposure nonhazardous for more than 50% of the persons exposed. The second is to recommend a system of monitoring audiometry to detect and remove from noise exposure those persons who show evidence of developing significant permanent threshold shifts.

Acceptable Noise Exposures

From Ward's descriptions it is clear that we do know fairly well some key relations between noise exposure and NIPTS, but this information is not adequate for the endless combinations of levels, durations, spectra, and rest periods encountered in many practical situations. We know much more about the relations between exposure to noise and temporary threshold shift (TTS). In 1961, Nixon and Glorig and Glorig, Ward, and Nixon noted for each of three noises that TTS two minutes after the end of an eight-hour exposure (TTS_2) at a test frequency of 4000 Hz was the same as the asymptotic NIPTS following 10 to 27.5 years of daily exposure to each of these noises. The observed relations suggested that noise exposures could be ranked in severity according to the amount of TTS they produced. There was even the possibility that the amount of TTS_2 would be reasonably predictive of the amount of NIPTS. Glorig, Ward, and Nixon proposed that noise exposures producing less than 12 dB TTS_2 for 2000 Hz might be considered safe and they drew some general purpose, limiting, noise-exposure contours based on the sound-pressure levels in the 600-1200 Hz octave band.

This same strategy was subsequently used in more detail by CHABA Working Group 46 for their 1965 report which was reprinted in 1966. First they adopted a median NIPTS of 10 dB for frequencies of 1000 Hz and below, of 15 dB at 2000 Hz, and of 20 dB at 3000 Hz and above, as their primary criterion for damage to hearing. This choice reflected (1) the usual emphasis on the preservation of hearing for speech, (2) a consensus among members of the group that hearing at 3000 Hz does contribute significantly to the ability to hear and to understand speech, and (3) a conservative target for the median so that at least 80% of a population receiving the limits of acceptable exposure would have unimpaired hearing levels according to the AMA criterion.

The second step was to adopt a secondary criterion in terms of TTS_2 to be used in place of the primary criterion in terms of NIPTS. The same decibel values were chosen for TTS_2 as had been used for NIPTS. A wide variety of one-day exposures to noise that would produce this TTS_2 criterion was derived by using data from experiments in which TTS_2s were measured following controlled exposures to noise. Figure 2 shows equinoxious contours of noise spectra in terms of octave-band level and center frequency of the octave bands with duration of exposure as a parameter. For example, the TTS_2 produced by an octave band of noise centered at 2 kHz when the level of exposure is 85 dB SPL and the duration is 480 minutes should be equal to that at 88 dB SPL for 120 minutes, to that at 96 dB SPL for 30 minutes, or to that at 106 dB SPL for 7 minutes. The exposure described by each contour will, on the average, produce the criterion TTS_2. Decreases of either noise level or duration of expo-

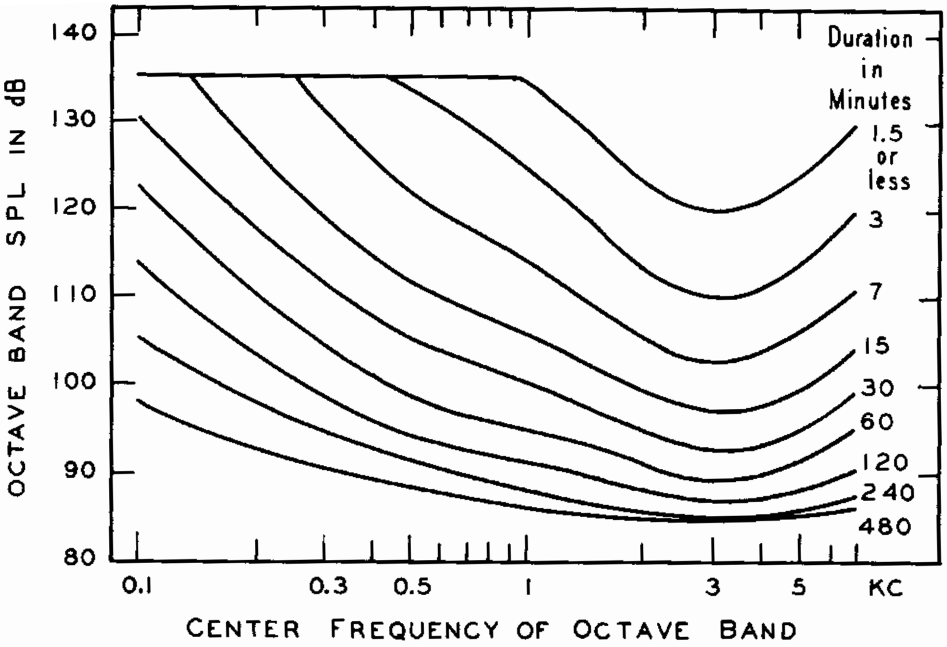

Figure 2. Each contour describes a set of octave-band levels at which an exposure for the duration indicated will produce average TTSs equal to the damage risk criteria for the various audiometric frequencies.

sure will result in less TTS and increases will result in more. This figure emphasizes the spectral dimensions of the relations and shows that for long durations the contour for octave-band level does not vary much with frequency, but for short durations, low-frequency noises up to 130 dB do not produce criterion TTS.

Figure 3 shows the octave-band levels as a function of logarithm of duration of exposure with frequency limits of the octave bands as a parameter. This figure contains essentially the same information as that in Figure 2, but emphasizes the role of duration in producing the criterion TTSs. Later we will show an example of a NIPTS at 4000 Hz of 28 dB that had been associated with daily exposures for 8 hours (480 min) to noise that included an octave-band level of 87 dB SPL for the 2400-4800 Hz band. On Figure 3 we see this level for this band exceeds the criterion contour at 480 minutes, but exposures at this level would not exceed the contour if the durations were less than 100 minutes daily. Other comparable figures that allow one to evaluate various intermittent and interrupted exposures to noise were contained in the CHABA report. Taken together, these contours constitute the reasonable and workable approximations to answers that have been so badly needed. When data concerning the relations of NIPTS to long-term exposures to noise are examined in terms of these limiting noise-exposure contours, it is clear that the contours are quite successful in defining safe and hazardous exposure

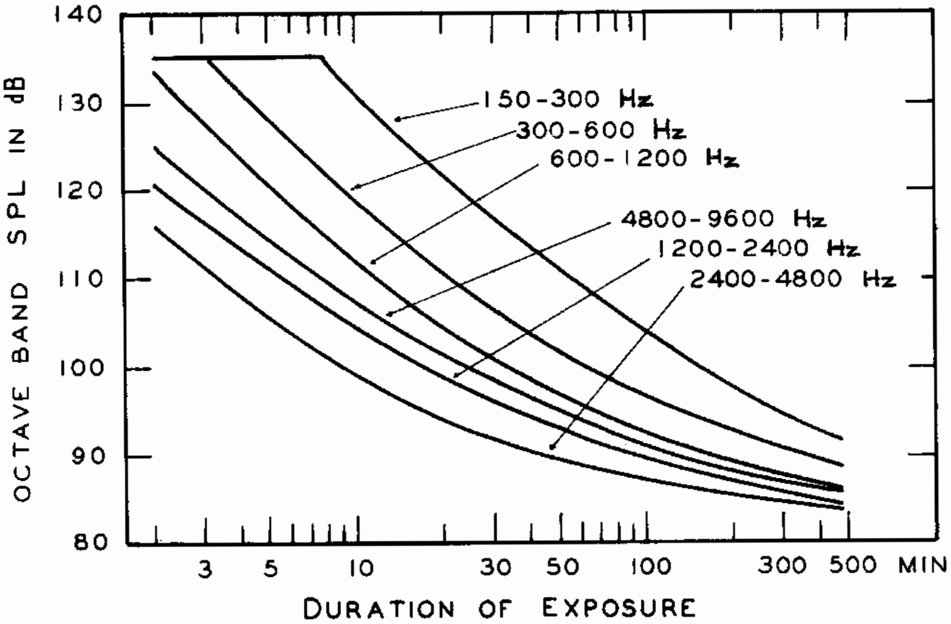

FIGURE 3. Each contour describes the set of band levels and exposure durations for the indicated octave bands that will produce average TTSs equal to the damage risk criterion for a corresponding audiometric frequency.

through a considerable variety of exposures. Accordingly the contours appear to have a considerable practical utility.

Botsford (1967) has rearranged the relations shown by these contours to simplify them in two ways. First he combined the contours for different octave bands and for interrupted and for intermittent exposures into a single set of contours. Then he carefully examined the spectral composition of commonly encountered manufacturing noises and, for these noises, was able to replace the specifications in terms of octave-band levels with specifications in terms of A-weighted sound-pressure levels. The loss of precision by these simplifications did not appear to be any larger than the usual lack of precision in the measurement of average sound-pressure level and duration of exposure.

Coles, Garinther, Hodges, and Rice (1968) have used TTS data in a similar way to specify safe and hazardous exposures to impulse noises produced by gunfire. In a statistical sense and within the stated limitations, their proposal has considerable practical merit. However, it does appear that people vary more widely in their susceptibility to TTS and to NIPTS when exposed to impulses than when exposed to steady-state noise. Some especially susceptible persons may show NIPTS after relatively few exposures to impulse noises. It may be difficult for monitoring audiometry to detect such persons before the onset of impairment.

Limitations and Reservations

These practical approaches leave some unsolved problems and some important reservations concerning the equinoxious contours. The strategy of using TTS_2 criteria in place of NIPTS criteria was based on three postulates:

(1) TTS_2 is a consistent measure of the effects of a single day's exposure to noise.
(2) All exposures that produce the same TTS_2s are equally hazardous.
(3) There is a correspondence between the magnitudes of TTS_2 for one day's exposure and NIPTS for 10 or more years of exposure that is close enough to justify using one to predict the other.

Though each of these postulates appears to be true, there is no clear evidence to support any of them. According to the second postulate, if a 10-dB TTS_2 is produced by a short, high-level exposure; an intermittent, medium-level exposure; or a continuous, 8-hour exposure, then each of these exposures sustained daily for years will produce the same NIPTS. In this regard we wish to emphasize that the criterion temporary threshold shifts of only 10 dB to 20 dB are quite small. If the postulate is in error by 50% for some exposures, the consequences are of little practical importance. But if one were to use a TTS_2 of 40 dB for a criterion, the same error could lead to important differences.

In Figure 4 we have drawn the regression of TTS_2 on NIPTS from the data on noises A, B, and C as reported by Nixon and Glorig (1961). This is a direct test of the third postulate. The spectral characteristics of these noises are shown in Table 1. At 4000 Hz, the TTS_2 was a very good predictor of NIPTS and the latter did not increase after about 10 years. At 2000 Hz, the TTS_2 after 8 hours of exposure to noise A should be 6 dB, but the median NIPTS after 10 years was only 2 dB, and after 27.5 years was only 4 dB. The mean TTS_2 after 8 hours exposure to noise B should be 18 dB, but the median NIPTS after 10 years was only 6 dB, and after 27.5 years was only 11 dB. The mean TTS_2 after 8 hours exposure to noise C should be 22 dB. After 10 years the median NIPTS was found to be only 13 dB in a manner consistent with the above trends. But after 27.5 years it had grown to 33 dB, a clear, step-like departure from the rest of the data. A similar step-like relation was observed in jute weavers by Taylor, Pearson, Mair, and Burns (1965). The trends for the 75th centile after 27.5 years clearly parallel those for the median. We do not understand the source of these nonlinearities, or steps, but clearly there are limits to the precision to be expected of the third postulate.

A second class of unsolved questions relates to our initial choice of a hearing criterion for damage. What are the relations between the magnitude of NIPTS and anatomical injury? Because a 10-dB to 20-dB change in threshold appears to make little difference for many hearing functions, many people, including ourselves, have been inclined to dismiss these changes as trivial. This may be a mistake. For example, during our studies of the relations between noise exposure and the behavioral auditory threshold in the chinchilla we recently encountered one chinchilla that appeared to have a slight hearing loss

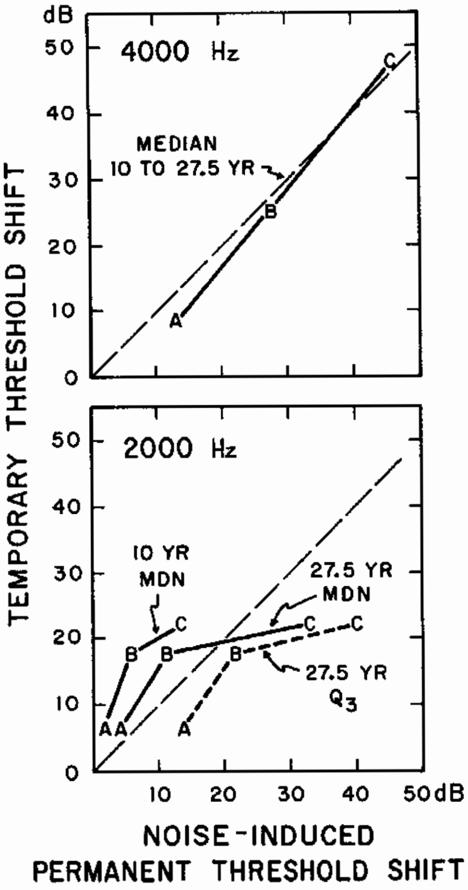

FIGURE 4. Noises A, B, and C are described in Table 1. At 4000 Hz, TTS$_2$ for each noise corresponds well with observed NIPTS. At 2000 Hz, NIPTS is not well predicted by TTS$_2$ (see text).

TABLE 1. Octave-band levels for noises A, B, and C in Figure 4 (from Nixon and Glorig, 1961).

Noise	*150–300 Hz*	*300–600 Hz*	*600–1200 Hz*	*1200–2400 Hz*	*2400–4800 Hz*
A	83 dB	84 dB	80 dB	80 dB	77 dB
B	88	88	90	88	87
C	89	93	94	94	96

compared to other, normal chinchillas. His audiogram is shown at the top of Figure 5. His thresholds were about 10 dB higher than normal up to 500 Hz, about 20 dB higher from 715 to 2000 Hz, and then almost normal at higher frequencies. These thresholds exceeded the normal range of variability only for the frequencies 715 Hz through 2000 Hz. The chinchilla did not appear to be in good health so he was not used in our series of experiments, but we did measure his cochlear potentials and prepare his ear for histological examina-

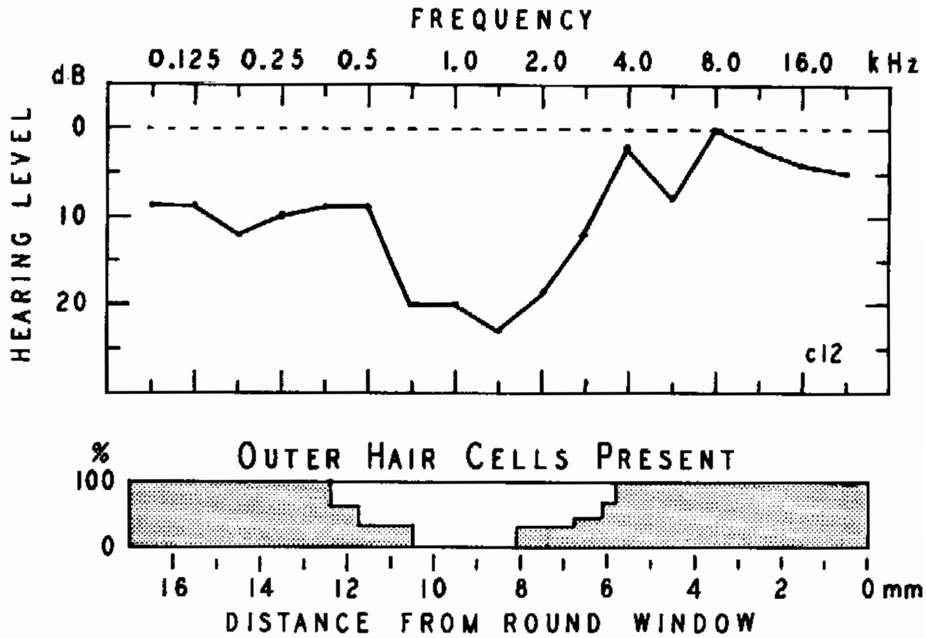

FIGURE 5. Above, audiogram of chinchilla c-12. Below, map showing percentage of normal outer hair cells present along the length of the basilar membrane of the inner ear.

tion. His cochlear potentials were low, and much to our surprise we found some loss of the sensitive outer hair cells through one-third of the length of the inner ear and total loss for a distance of about 2 mm. A map showing the area of missing hair cells appears below the audiogram and is lined up to show the approximate correspondence between anatomical cochlear location and auditory frequency. The correspondence was based on the place at which there is normally a 180° phase lag for the Bekesy traveling wave at each frequency. A loss of nerve cells accompanied the loss of sensory cells. Figures 6a and 6b show the essentially normal sense organ and neurons about 3.5 mm from the round window. The important features of these photomicrographs are the clear presence of three outer hair cells resting on their supporting cells in Figure 6a and a reasonably compact spacing of the cell bodies of the primary auditory nerve as in Figure 6b. Figures 6c and 6d show the corresponding structures about 8.5 mm from the round window. The outer hair cells are completely missing in Figure 6c, the supporting cells are not normal, and the inner hair cell may not be normal. The cell bodies of the auditory nerve corresponding to this area are widely spaced in Figure 6d. This apparent lack of a normal number of nerve cells was confirmed by careful counts of these cells throughout the ear.

We do not know why this ear was not normal. It is possible for exposure to aircraft noise around airports and during shipment by air to have produced this

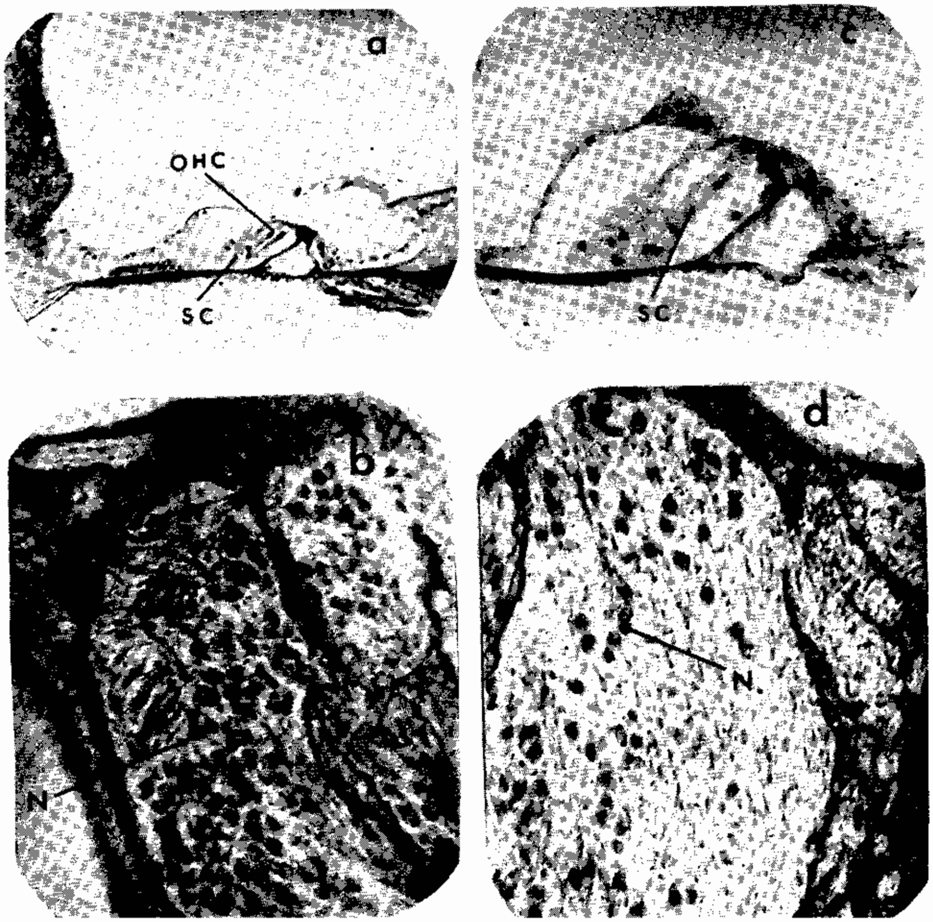

FIGURE 6. a. Normal organ of Corti of inner ear. b. Normal spiral ganglion of nerve cells. Both are about 3.5 mm from round window. c. Abnormal organ of Corti. d. Abnormal spiral ganglion. Both are about 8.5 mm from round window. Note absence of outer hair cells and relative absence of nerve cells. OHC = outer hair cells. SC = supporting cells. N = cell bodies of primary auditory nerves.

injury in a chinchilla. However, from the point of view of our subject today, the important point is that a small deviation from normal threshold may sometimes represent a comparatively large anatomical defect. It is possible that a 10-dB to 20-db NIPTS in man also represents an anatomical defect of this size or severity. The impairment of the function of hearing for pure tones associated with this defect is not significant. However, we do not know as much as we should about how such a defect combined with environmental noise or other medical conditions affects the perception and understanding of everyday speech. For this reason our criteria for damage and risk should be reviewed periodically as we learn more about the ear, hearing, and the relations of each to noise exposure.

Concluding Notes

It would be wrong to leave this discussion of acceptable noise exposures and damage risk criteria on a completely negative note. We do know that some exposures are safe and others are certainly hazardous. We can specify in terms of a TTS criterion rather detailed equinoxious contours for limiting exposures to noise. These noise exposure contours may provide accurate guides to safety even though the underlying postulates may be somewhat in error. Other key relations can be postulated to fit the same general sets of observations. For example, there is some evidence that thresholds recover to normal within about 5 hours after a TTS_2 of 10-20 dB but may require 16 hours or more to recover from larger threshold shifts. If this were generally true, we could postulate that noise exposures producing TTSs which disappear in about 5 hours can be safely repeated daily for years. As a corollary, daily noise exposures that leave a residual TTS at the start of the next day's exposure are quite probably hazardous. We get the same sets of equinoxious contours from these postulates as we got from those cited earlier.

From a practical point of view it does not matter why equinoxious contours are helpful when, in fact, they seem to be. Ward concluded earlier today that noise environments below 80 dBA were certainly safe; that for many long-term exposures at 95 dBA there is a probability of impairment in about 50% of the persons exposed; and that at 105 dBA, steady, continuous exposure produces losses in nearly all men. Given this frame of reference, the equinoxious contours based on TTS data allow us to chart our way through the complexities introduced by brief exposures, rest periods away from noise, etc., and provide the best guides to safety that we have.

References

Botsford, J. H., Simple method for identifying acceptable noise exposures. *J. acoust. Soc. Amer.*, **42**, 810-819 (1967).

Coles, R. R. A., Garinther, G. R., Hodge, D. C., and Rice, C. G., Hazardous exposure to impulse noise. *J. acoust. Soc. Amer.*, **43**, 336-343 (1968).

Glorig, A., Ward, W. D., and Nixon, J. C., Damage risk criteria and noise-induced hearing loss. *Arch. Otolaryng.*, **74**, 413-423 (1961).

Guide to the evaluation of permanent impairment: ear, nose, throat and related structures. Committee on Medical Rating of Physical Impairment. *J. amer. med. Ass.*, **177**, 489-501 (1961).

Hazardous Exposure to Intermittent and Steady-State Noise: Report of Working Group 46, NAS-NRC Committee on Hearing, Bioacoustics and Biomechanics. January 1965.

Kryter, K. D., Ward, W. D., Miller, J. D., and Eldredge, D. H., Hazardous exposure to intermittent and steady-state noise. *J. acoust Soc. Amer.*, **39**, 451-464 (1966).

Nixon, J. C., and Glorig, A., Noise-induced permanent threshold shift at 2000 cps and 4000 cps. *J. acoust. Soc. Amer.*, **33**, 904-908 (1961).

Principles for evaluating hearing loss: report of the Council on Physical Medicine and Rehabilitation. *J. amer. med. Ass.*, **157**, 1408-1409 (1955).

Taylor, W., Pearson, J., Mair, A., and Burns, W., Study of noise and hearing in jute weaving. *J. acoust. Soc. Amer.* **38**, 113-120 (1965).

Message Constraints, A Neglected Factor In Predicting Industrial Speech Communication

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Speech communication by industrial workers is, it seems to me, a more complex subject than questions of noise level, distance, and telephone circuits. The worker is often where large machines and heavy materials are manipulated in some process. His work can involve hazards to life and limb; these hazards may be aggravated by noise. Interference with shouted warnings or with normal routine speech messages can cause serious accidents. I consulted my colleagues to find out what was known about such incidents. They said that not only was there no information about the relationship between industrial accidents and speech communication but, as far as they knew, none about noise and accidents.

This left the field for my talk almost completely open so I decided to talk about a critical communication factor which I feel has received only preliminary study. We already have much of the information we need about the physical measurement of noise and speech and about the relationship of these measures to speech reception and to ratings of annoyance. These data have great value for many purposes but they probably cannot be used to gain detailed insight into the interaction of the factors that determine speech communication performance in actual industrial situations.

Every speech situation is a complex of noise and speech characteristics and, most important of all, of the current constraints on message selection and reception. Does the talker use a standard, routine language? Does the listener know the language? Does the situation routine contribute to reception? These aspects of message constraint can affect communication and greatly vary the effects of the physical noise conditions. First I want to describe some fairly obvious types of constraint. Then I will briefly review some studies of their effects. After that I hope you will agree with me that the specification of "acceptable noise level" should include specifications of message constraints.

Types of Message Constraint

Linguistic Constraints. The most indispensable characteristic of speech communication acts is their systematic, patterned structure. First of all, speech communicators expect messages to be given in an agreed-upon language. Also, the language itself is a structured system with certain expected and partially predictable patterns of sounds, of syllables, of words, of phrases, of statements, of commands, or of questions. These patterns are general linguistic constraints which are literally the basis on which a language works.

Situational Constraints. There is another class of constraints which supports speech communication. These depend on the predictability of the particular situation or operation which prompts the communicators to speak. These situational constraints can vary widely; they vary greatly between situations and they may also vary from time to time in the same situation or operation.

Situational constraints are of the utmost importance to job-related communication between workers. If the job is such that the situational constraints are very high, then almost no communication is necessary. Sometimes, in such cases, workers do not need the flexibility of speech communication. If the noise level is very high and/or the distance between workers great, then, in these highly constrained situations, a few visual signs are all that is needed for communication. Classic examples of situations like this are weaving industries where visual indicators are used, and crane operations where the "hooker" below signals with arm and hand gestures to the crane operator who is too far away or in too much noise.

There are two ways that job situational constraints may be fewer, thereby requiring a greater variety of communication. One way is through the occurrence of rare or emergency deviations from the normal routine of the job operations; then successful communication can serve to avoid an accident. The accident may be merely a minor goof or it may be a major catastrophe to men, machines, or materials. Thus the possible deviations from a job routine need to be evaluated and then appropriately weighted in any assessment of the speech communication needs for that job.

It is the deviations from routine that can make speech communication the method of choice with its inherent flexibility and readiness without special experience of training.

The second way that situational constraints may be lowered is through increased complexity in the situation itself. Here the job operations themselves may be less routine or they may be subject to unpredictable influences not arising directly from the job operations themselves. As situational constraints of this type are lessened, speech communication becomes a more important part of the job. For complex but routine operations, special vocabularies and phrases may be developed to help reduce complexity and increase communication efficiency. A good example of this is air-traffic control communication. For highly unpredictable job operations, speech is almost the sole means of communication, and vocabularies and expressions may change rapidly; a good example would be the job of a salesman, where flexibility, sensitivity, and originality in speech communication can be major factors in the success of the job operations.

When situational constraints are extremely high, a very high noise level may be tolerated without unduly affecting communication. Conversely, in highly unpredictable communication situations the worker demands the lowest possible noise level and, if possible, face-to-face communication.

Studies of Message Constraint

Beyond a few good laboratory experiments little information is in the literature which would form a basis for practical performance estimates of speech communication in real-life industrial situations. Workers naturally develop special communication vocabularies and procedures, and pass them on to new workers. These special languages are of considerable value in many cases. However, as far as I could determine, no careful studies have been made of industrial situations to describe types of special communications procedures, their relationships to different job operations, or their effectiveness in improving either communication or job performance. Perhaps one reason, suggested to me by Allan Cudworth, is that the noisiest industries tend to be low-profit operations which cannot afford expensive surveys of communication problems. On the other hand, who can say how expensive is our current ignorance of industrial speech communication? Until we know what time and materials are wasted due to faulty speech communication, we are not really able to judge the relative cost of further research.

In aviation, however, losses due to poor communication can be dramatic, instead of gradually cumulative. A large portion of aviation is operated at a deficit; the best illustration is military aviation. Accordingly, every aspect of speech communication in aviation has received fairly careful study. Much of the speech communication data presented at this symposium was gathered with reference to and support from military aviation.

A notable exception to the statement that industries cannot afford detailed study of speech communication is the American Telegraph and Telephone Company—of course their entire business is speech communication. And it is especially interesting to note that Bell Telephone Laboratories performed what was probably the first study on message constraints in actual speech communication. This was a study by French, Carter, and Koenig in 1929, of the words occurring in telephone conversations. They found, for example, that the 500 most common words accounted for 95% of all words in the conversations. The same most-common-500 criterion in written texts yields only 77% of all the words. Thus conversations are measurably more constrained than written material.

Now we turn to work on special language constraints that are largely situational. Fortunately, we have a good model for industrial studies of situational message constraints in a study by Frick and Sumby on the language of control tower operators and aircraft pilots (Frick and Sumby, 1952; Sumby, 1960). First they collected a large sample of message interchanges between tower and pilots. The words and phrases in the messages were then grouped into operational types. Examples of two types were the pilot's aircraft identification, e.g., "Air Force 1234," and the tower's landing instruction, e.g., "Runway one zero." It was found that only 13 different types of phrases occurred. Thus, although ordinary English words were used, the phrases actually employed were only a tiny fraction of all possible English phrases.

Even more important was a further finding that, given the situation and one phrase, the pilots could predict with 77% success what the next phrase would be. If two phrases were given, prediction success was very high, namely 83%. Thus Frick and Sumby found that, in specialized practice, speech communications may under ideal conditions actually convey little information that is not predictable from a knowledge of procedures and the current situation. As they put it, control-tower speech communication may serve much of the time merely as a monitoring arrangement. Figure 1 shows how Frick and Sumby summarized the high predictability of tower language compared with English as a whole.

In actual practice, the current messages, if independent of situational context, may be poorly understood if received word-by-word at random. This

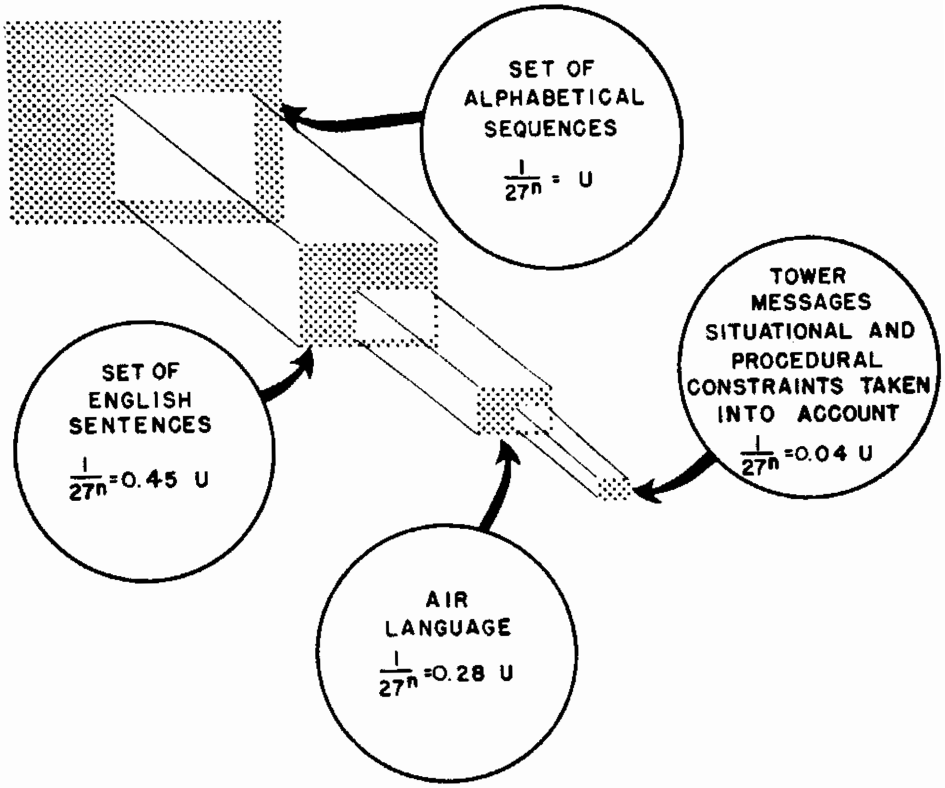

FIGURE 1. Estimated proportions of the total predictive uncertainty, *U*, of English letter sequences, depending on the constraint imposed by three conditions: (1) that the sequences make sentences, (2) that the sentences are all from control tower "air" language, or (3) that a given air traffic control situation exists, as the conditions are defined in the study of Frick and Sumby (1952) from which this figure is taken. The final stage of constraint is estimated to have only 1/25th or 0.04 tne predictive uncertainty of the original set of letter sequences. That is, the tower messages, in their context, are about 25 times as predictable as English letter sequences.

was indicated in a study by Beitscher and Webster (1956) where the individual, isolated word intelligibility over air traffic control circuits turned out to be surprisingly low. Tower-to-plane words averaged 74% correct while plane-to-tower words average only 44% correct. High noise, circuit distortion, and limited bandwidth are the reasons for such low performance. The situation routine enables flyers to tolerate such poor reception of their words, but can you imagine a salesman or a production manager who would be happy with having only half his words heard correctly?

Laboratory studies have attempted to quantify the effects of contextual constraints and their interactions with noise and circuit variables.

The classic study of Miller, Heise, and Lichten (1951) determined interactions between speech-to-noise ratio and the size of the test vocabulary; I carried out a similar study with transmission bandwidth as a circuit variable (Pickett, 1961). Results of both studies are shown in Figure 2. It will be noted that, depending on the complexity of the context, here varied by increasing the number of possible words, either the band or the S/N ratio necessary for successful transmission, say at a level of 90% correct, can vary over a very

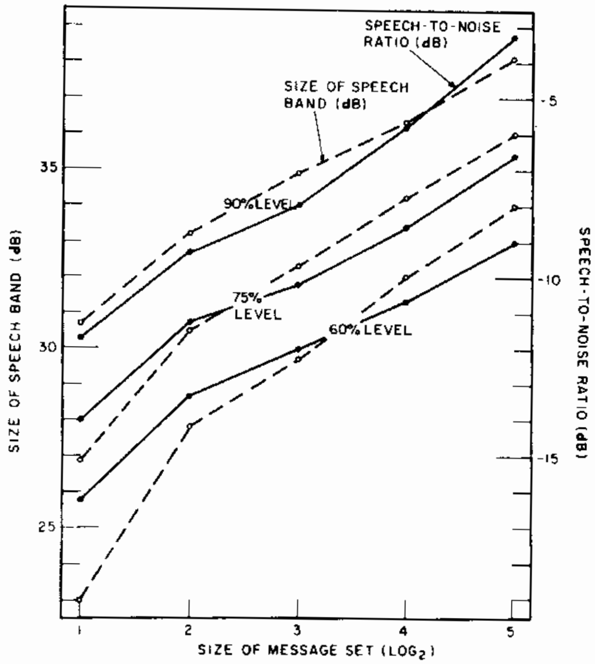

Figure 2. Relations between the transmission conditions (speech-to-noise ratio as solid-line curves, or speech bandwidth in dB as dotted-line curves) and size of message set in numbers of words, for obtaining given levels of correct transmission, 90%, 75%, or 60%. As the message constraint decreases, that is, as the size of message set increases from 2 words to 32 words, the size of band and/or the speech-to-noise ratio must be increased in order to maintain the desired level of correct transmission (from Pickett, 1961).

wide range, for example, -12dB S/N ratio for sets of two words ($\log_2 = 1$) but a -3dB S/N ratio for a set of 32 different words ($\log_2 = 5$).

Data of this type provide at least a preliminary basis for estimating communication performance in an industrial situation—given the complexity of context, the speech-to-noise ratio, and the bandwidth of the transmission circuit.

Pollack and his coworkers, Rubenstein and Decker, have recently explored some more complicated aspects of message constraints in speech communication (see bibliography for these and other background studies). One study by Pollack (1964) is especially relevant to a real-life communication problem, the problem of rare, unexpected messages occurring in an otherwise routine flow of communication. In Pollack's experiment, small word-sets were used in which some of the words occurred very frequently while others occurred only rarely. The listeners knew the words and the exact likelihood of occurrence of each word in a test set. Figure 3 shows the results of such a test. The probability of the stimulus word is plotted against the horizontal scale from a low rate of occurrence of once in 240 stimulus words (stimulus word probability, $p = 0.004$) to a high rate of occurrence of once in every two words ($p = 0.50$). The main effect is that the reception of the rare words, those occurring at 1 in 30 ($p = 0.033$) or less, is a great deal lower than that of the more frequent words, 1 in 16 or more ($p = 0.063$); this occurred even at favorable speech-to-noise ratios. In other words, the more frequent words dominated the

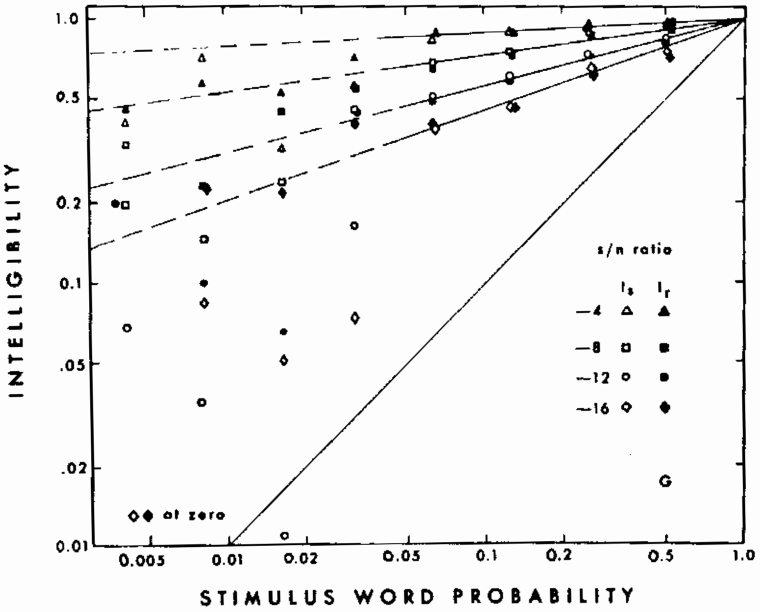

FIGURE 3. Effects of word probability on word intelligibility at various s/n ratios. Words that occurred rarely in these tests (data points in left half of graph) were received with much lower intelligibility than the more frequent words (from Pollack, 1964).

situation at the expense of the rare words. In fact the listeners chose the rare words as responses far less frequently than their known frequency of occurrence. (Figure 4). For example at the two lower S/N ratios the rare words occurred as stimuli about three times as often as they did as responses.

It is apparent from Pollack's tests, which were, incidentally, fairly extensive and included a number of controls, that the rare message problem may be worse than we would expect; and this might be especially so since rare messages may be reserved for emergency situations.

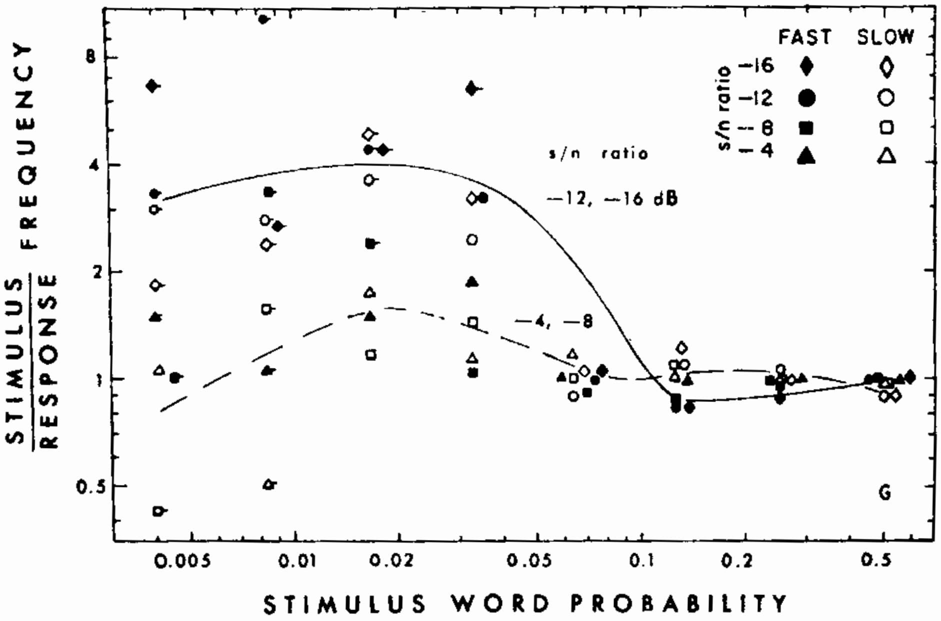

FIGURE 4. The ratio of stimulus word frequency of occurrence in Pollack's tests to frequency of occurrence as a response (plotted against the vertical scale) as a function of word probability, and at various speech-to-noise (s/n) ratios. The stimulus/response ratio is close to one for the most frequent words, meaning that they are given as responses just about as often as they occur as stimuli. However, the more rare words (left half of graph) are given as responses only about half (stimulus/response ratio = 2) as often as they occurred, at the higher s/n ratios, and only about one-quarter as often at the lower s/n ratios (from Pollack, 1964).

Recommendations

It is appropriate now to specifically list the studies needed to improve prediction of industrial speech communication.

1. Survey and study relations between noise levels, accidents, and communication breakdowns.
2. Study types of industrial speech communcation in regard to their linguistic and situational constraints.

3. Study the natural speech communication behavior of people in situations having varying degrees of predictability, including factors of learning, adaptation, boredom, and fatigue.

The research to be done is complex and extensive, but until we have better information on such basic factors, noise ratings for speech communication situations will be severely limited in their usefulness.

Bibliography

Attneave, F., Psychological probability as a function of experienced frequency. *J. exp. Psychol.,* **46,** 81-86, (1953).

Beitscher, H. R., and Webster, J. C., Intelligibility of UHF and VHF transmissions at fifteen representative air traffic control towers. *J. Acoust. Soc. Amer.,* **28,** 561-564 (1956).

Berry, J., Some statistical aspects of conversational speech. In W. Jackson (Ed.), *Communication Theory.* London: Butterworth Sci. Publ., 392-401 (1953).

Felton, W. W., Fritz, E., and Grier, G. W., *Communication Measurements at National Airport.* Tech. Rep. 1-2185-2. Philadelphia: Franklin Inst. (1953).

French, N. R., Carter, C., and Koenig, W., The words and sounds of telephone conversations. *Bell Teleph. Sys. Tech. J.,* **9,** 290-324 (1930).

Frick, F. C., and Sumby, W. H., Control tower language. *J. Acoust. Soc. Amer.,* **24,** 595-596 (1952).

Goldman-Eisler, F., Speech production and language statistics. *Nature,* **180,** 1497 (1957).

Howes, D., On the relation between the intelligibility and frequency of occurrence of English words. *J. Acoust. Soc. Amer.,* **29,** 296-305 (1957).

J. verb. Learn. verb. Behav. Search all issues for recent research on relevant psycholinguistic aspects of speech communication.

Miller, G. A., Heise, G. A., and Lichten, W., The intelligibility of speech as a function of the context of the test materials. *J. exp. Psychol.,* **41,** 329-335 (1951).

Pickett, J. M., *Effects of Transmission Band and Message Context on Speech Intelligibility.* Rep. 5890 Washington, D. C.: U. S. Nav. Res. Lab. (1961).

Pollack, I., Message uncertainty and message reception. *J. Acoust. Soc. Amer.,* **31,** 1500-1508 (1959).

Pollack, I., Message probability and message reception. *J. Acoust. Soc. Amer.,* **36,** 937-945 (1964).

Pollack, I., Message uncertainty and message reception. II. *Lang. Speech,* **3,** 174-177 (1960).

Pollack, I., Rubenstein, H., and Decker, L., Intelligibility of known and unknown message sets. *J. Acoust. Soc. Amer.,* **31,** 273-279 (1959).

Rubenstein, H., Decker, L., and Pollack, I., Word length and intelligibility. *Lang. Speech,* **2,** 175-178 (1959).

Sumby, W. H., The control tower language: A case study of a specialized language-in-action. *Lang. Speech,* **3,** 61-70 (1960).

Wiener, N., Speech, language and learning. *J. Acoust. Soc. Amer.,* **22,** 696-697 (1950).

Control of Industrial Noise Through Engineering

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Industrial noises can cause partial deafness, interfere with communication by speech, and be annoying. Reducing the noise to acceptable levels is the best way to avoid these undesirable effects. The principles of noise reduction are well established and wider engineering application of them can provide the lower levels required in many instances.

Over 15 years ago a comprehensive noise survey of manufacturing industries was undertaken (Karpus and Bonvallet, 1953). Forty plants were selected from 12 manufacturing industries; detailed noise surveys in these 40 plants produced 580 noise measurements. The data were reported as octave-band sound-pressure levels and, for simplification, each analysis was converted to the A-weighted sound level (Peterson and Gross, 1967), which is becoming widely recognized as a valid indicator of human response to noise (Botsford, 1967a, 1967b, 1968; and Thiessen and Olson, 1968).

Figure 1 shows the cumulative distribution of the A-weighted sound levels

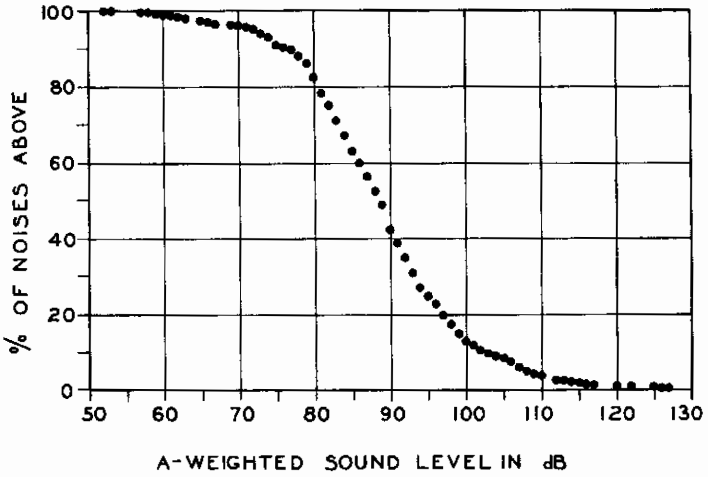

FIGURE 1. Distribution of sound levels in manufacturing industries (based on survey by Karplus and Bonvallet, 1953). Each point on the vertical scale indicates the percentage of noises that exceeded the corresponding level on the horizontal scale.

obtained. Each point indicates on the vertical scale the percentage of the noises that exceeded the corresponding level on the horizontal scale. The curve shows that about half the noises had levels of 90 dBA or higher and would be regarded as potentially harmful to hearing by present criteria. Relatively few of these noises had really high levels. Many of these noises were intermittent with sufficient interruptions to render them harmless (Botsford 1967a). Although this survey gave no information on how many employees were exposed to each of these levels and may not depict accurately the noises of industry today, the survey does indicate that probably many harmful exposures exist. It is interesting to note that reducing all noises only 6 dBA would halve the number falling in the potentially harmful range of 90 dBA or more. Reducing all noises by 20 dBA would practically eliminate the problem. Such reduction, I believe, should be the engineering goal.

Responsibility for Noise Reduction

Noise reduction is generally considered the responsibility of the employer, who is obligated to provide a safe workplace. He, of course, should do all that is feasible to reduce excessive noise, but we must recognize there are severe limitations on what the employer can accomplish. Operations designed without regard for noise exposure of employees are frequently constructed in ways that preclude noise control. Often, costly alterations would be required for which no capital is available. In these situations, personal protective equipment offers the only practical solution.

Programs for modernization of facilities or new construction when noise can be considered in the design of operations and selection of equipment provide the best opportunities for noise control. But the possibilities for noise control are still limited since materials and equipment currently available embody little consideration of noise control.

At this point much of the responsibility for noise control is transferred from the operator to the manufacturer of noisy equipment. Legal precedents affirm that the manufacturer is obligated to incorporate safety features into his product to reduce the possibility of injury to the user. Yet manufacturers have not given the necessary corrective attention to excessive noise as a hazardous attribute.

Both manufacturers and operators of noisy equipment should eliminate objectionable noises where practical. Both also should consider probable noise levels of new designs, then incorporate features that will keep personnel exposures to noise at acceptable levels.

Noise Reduction Principles and Applications

The principles of noise control have been explained in very practical terms by Tyzzer (1953) and also in great technical detail by Harris (1957), and only a cursory discussion is required here.

The pulsations in atmospheric pressure the ear perceives as noise can originate with an aerodynamic disturbance such as the turbulence produced inside a blower. More often noise is generated by the vibration of some structure that produces sound waves in the adjacent air. In either case, it is obvious that noise generation can be reduced by lessening the disturbance causing it, whether this be turbulence or vibration.

Vibration of a structure is dependent on its rigidity, which is usually prescribed by nonacoustical considerations. There are two types of materials that can be used to control this vibration. One is a soft material, like rubber, that reduces the transmission of impact or vibration from one point to another by yielding rather freely to the impressed forces. The other is a viscous or frictional material, like automotive undercoating, that is applied to the structure to create resistance to the vibratory motion.

Similarly, there are two types of materials to control sound escaping from a source: One is a solid material, like steel, that blocks transmission of sound. It is impermeable by the pressure pulsations of sound waves and unyielding to the forces they produce because of its rigidity and inertia. The other is a porous material allowing incident sound waves to penetrate and be absorbed or dissipated by resistance to air flow through the pores of the material.

Proper use of these four materials can solve noise problems after analysis of the noise source to determine how the noise is generated and transmitted. Many examples of practical application can be found in the literature (*Journal of the Acoustical Society of America* and *Engineering Index*), so only a few need be described here.

One example is six 1500-horsepower blowers, each of which drew air from outdoors through a glass fiber filter. Noise generated by turbulence within each blower escaped through the porous intake filter to an office across the street where it interfered with telephone conversations. Intense blower noise inside the discharge piping was transmitted through the thin pipe walls, producing objectionable levels in adjacent areas. Figure 2 indicates the methods used to reduce the noise of each blower to an acceptable level. To reduce the escape of noise through the intake, the baffle shown at the left was constructed over the intake grille. The baffle consisted of corrugated steel siding to block transmission of blower noise toward the office and was lined with a sound absorbing material to prevent reflection of blower noise outside the baffle. Open spaces were left at the top and bottom of the baffle to admit intake air, and vent lines were terminated under the baffle to confine the noise of occasional discharge of excess air. Inside the building, radiation of noise from the pipe was reduced by means of a special covering. A 2-in. layer of low-density fiberglass was attached to the pipe and covered with a double layer of roofing felt. This heavy, air-tight skin, isolated from the pipe by the soft fiberglass, formed an effective noise barrier that reduced levels nearby dramatically. The special pipe-covering undoubtedly reduced pipe wall vibration, also, by offering frictional opposition.

Buildings that will house noisy operations can be constructed of sound-absorbing materials that will minimize sound reflection and reverberation inside the building. Several manufacturers offer acoustical roof decks and

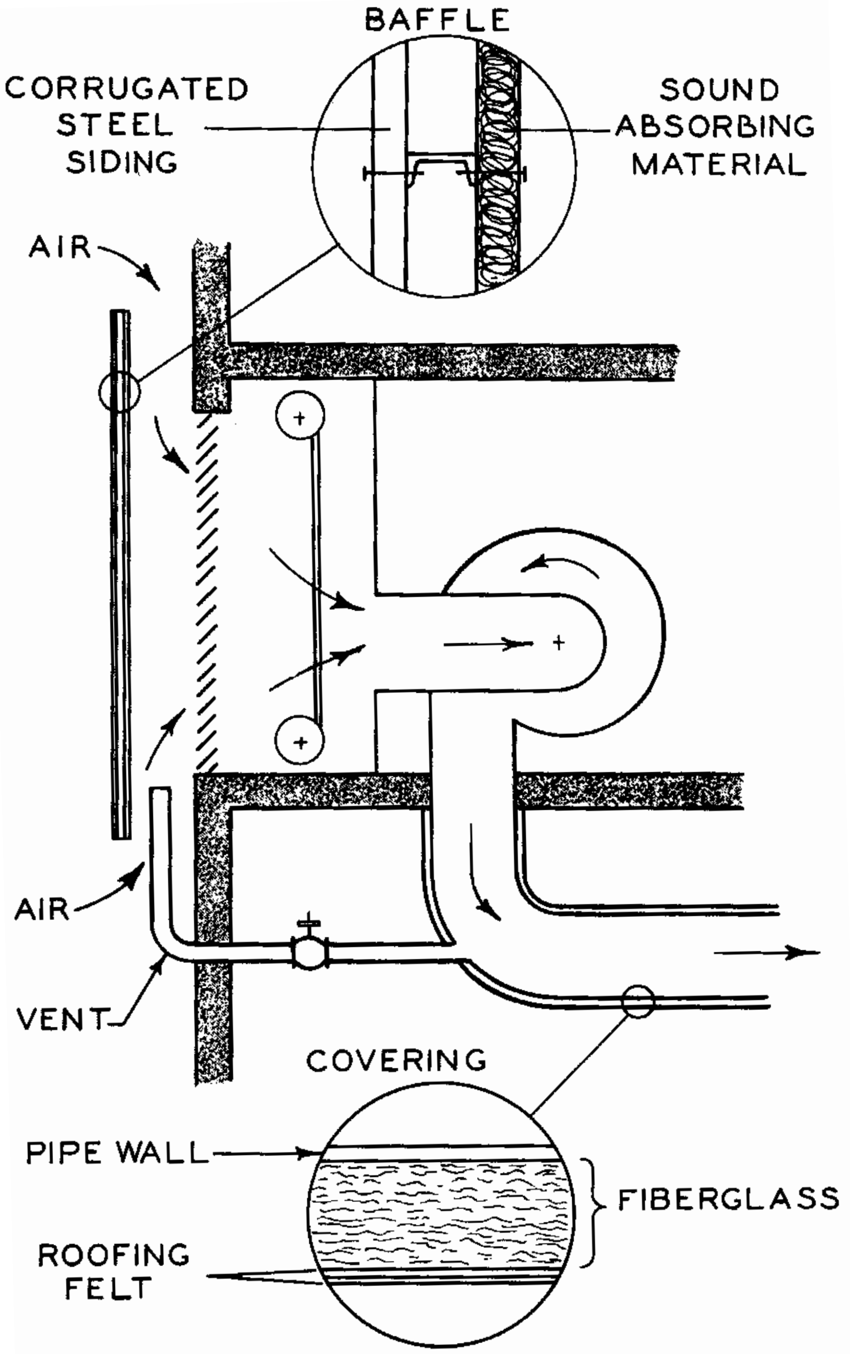

FIGURE 2. Arrangements for controlling blower noise. The baffle covering the intake prevents escape of blower noise outdoors and the special covering of the discharge pipe prevents the intense blower noise inside from escaping.

curtain walls for such applications. Concrete forms can be constructed of acoustical boards that may be left in place to provide sound absorption within the completed space. Frequently, reverberant noise can be controlled at harmless levels everywhere except near noise sources. Controlling reverberant noise with sound-absorbing construction materials will simplify containing noise from prominent sources that are discovered after operations commence; often a barrier will prevent the spread of noise from some sources, though, without a sound absorbing building interior, total enclosure would be required to provide the same noise reduction.

Purchasers can encourage manufacturers of noisy equipment to produce quieter products by requesting that product noise data be supplied with quotations or by including noise specifications in purchase requisitions. This approach has been successful in obtaining quieter products from manufacturers of excavating and hauling equipment used in mining. In these instances, purchase orders have specified maximum octave-band noise levels equivalent to about 90 dBA at the operator's location. Standard equipment could usually meet this requirement after some superficial modifications. Installation of an effective muffler on the engine exhaust provided most of the desired noise reduction. Additional noise reduction was obtained by closing holes in the partition separating the operator from the engine and by adding sound absorbing materials to the engine and operator compartments. The average noise reduction obtained with such modifications was 8 dBA. None of the equipment purchased recently using the noise specification produces harmful noise exposures.

Accelerating Progress

From the volume of literature dealing with industrial noise problems that has accumulated over the past 20 years, it would seem that occupational hearing loss would be under good control. However, a recent survey of industrial hearing conservation reported that of 600 companies queried only 53 reported having fully-developed occupational hearing loss control programs (Rintelmann and Gassaway, 1967). Twenty-three more reported having limited programs. From the lack of interest in noise abatement these findings imply, it is easy to understand why the manufacturers of noisy industrial equipment have done so little to provide quieter products.

To accelerate progress toward elimination of occupational hearing loss, three steps are needed:

1. Simplification of noise information is required to make it more readily usable by those in positions to take effective actions. Acoustical knowledge has always been presented in the complex language of the scientists who developed it, frequently in needlessly elegant detail. There is little wonder that the subject is so poorly understood by engineers and the public. Reduction of acoustical science to terms of engineering practice is necessary.

2. Education in all aspects of noise must be greatly expanded. Engineering courses dealing with noise and vibration are almost nonexistent in college curricula and should be added. A textbook presenting current knowledge in a form suitable for engineering use with laboratory experiments and homework problems is needed for use by the nonexpert instructors who must teach these courses.

   Several short courses on noise control are held across the country every year, usually during the summer at colleges and universities. These courses can be very effective in providing the education needed by practicing engineers, but some fall short of their potential attainment. Sometimes the course director uses faculty appointments as patronage for his consulting clients who may not be the best instructors. These short courses should be upgraded as required and continued.

3. Standardization of noise control methods is required. Specifications for noise and hearing measuring instruments have been developed within the United States of America Standards Institute by the Acoustical Society of America. Other noise standards, some dealing with human responses, are in preparation. An intersociety committtee has developed some "Guidelines for Noise Exposure Control" (1967) to direct occupational hearing loss prevention efforts, and the American Conference of Governmental Industrial Hygienists intends to translate these guidelines into specific limits for noise exposure (Jones, 1968). These efforts help to establish guidelines of good practice for all to follow and need to be intensified and augmented.

References

BOTSFORD, J. H., Simple method of identifying acceptable noise exposures. *J. acoust. Soc. Amer.*, **42**, 810-819 (1967).

BOTSFORD, J. H., Predicting speech interference and annoyance from A-weighted sound levels. *J. acoust. Soc. Amer.*, **42**, 1151 (1967).

BOTSFORD, J. H., The weighting game. *J. acoust. Soc. Amer.*, **44**, 381 (1968).

Engineering Index. See index of papers, contemporary literature and patents.

Guidelines for noise exposure control. *Amer. ind. Hyg. Ass. J.*, 418-424 (1967).

HARRIS, C. M. (Ed.), *Handbook of Noise Control*. New York: McGraw-Hill (1957).

JONES, H. H., Physical agents committee's proposal for limits of noise exposure. Paper read at Amer. Ind. Hyg. Conf., St. Louis, Mo. (May 1968).

Journal of the Acoustical Society of America. See index of papers, contemporary literature, and patents.

KARPLUS, H. B., and BONVALLET, G. L., A noise survey of manufacturing industries. *Amer. ind. Hyg. Ass. Quart.*, **14**, 235-263 (1953).

PETERSON, A. P. G., and GROSS, E. E., Jr., Handbook of noise measurement. (6th Ed.) *Gen. Radio Co.*, 58 (1957).

RINTELMANN, W. F., and GASSAWAY, D. C., A survey of hearing conservation programs in representative aerospace industries. *Amer. ind. Hyg. Ass. J.*, 372-380 (1967).

THIESSEN, G. G., and OLSON, N., Community noise—surface transportation. *Sound Vibration*, **2**, 10-16 (1968).

TYZZER, F. G., Reducing industrial noise, general principles. *Amer. ind. Hyg. Quart.*, **14**, 264-285 (1953).

Control of Industrial Noise Through Regulation and Liability

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The solution of any legal problem rests on the recognition of simple basic concepts.

Costigan, one of the great legal writers of the first half of this century, said that all laws were simply a codification of the principles of the Ten Commandments; that any law which failed to follow these principles would prove unenforceable and would be more violated than honored and eventually discarded.

Laws, to preserve and enhance man's enjoyment of the values of life, must be delicately but firmly interwoven into the fabric of his environment. The control of industrial noise from a legal standpoint depends on weaving into the matrix of industrial relations the concept that a workman shall not suffer harm from exposure to noise in his working environment and the corollary concept that he be compensated for harm if sustained.

The two concepts of law are now universally accepted and the problem now is to make them effective by weaving them into the industrial working environment.

Two types of statutes may be employed to save employees from harm and to compensate them for harm if sustained. In one type of statute the legislature delegates to and confers upon a constitutional agency of the state the power and duty of prescribing detailed rules and regulations to implement the broad purposes of the law (avoidance of and compensation for harm) as enacted by the legislature. In the second type of statute the legislature itself in detail prescribes regulations to prevent harm from noise and the conditions under which and the extent to which benefits shall be granted if harm be sustained.

A state may enact a statute blending these two types of statutes, extending general authority to appropriate agencies but prescribing certain definite requirements in the statutory law which the legislature believes of sufficient importance to make explicitly a matter of state policy—not to be left to the judgment of a lesser governmental agency.

Whatever approach is taken, due process is mandatory before either type of program is adopted. Interested parties must be given ample notice of proposals intended to be adopted and given an opportunity to be heard either before the legislature or the regulatory agency preceding final adoption.

In considering the legal problems of industrial noise, it is logical first to consider prevention of harm and later to consider compensation for harm sustained.

Monetary benefits which must be paid for harm sustained provide a well-recognized incentive for employers to prevent such harm. But employees are generally harder to convince of the need to act in their own self-interest, except after harm has been sustained. Since harm can be precluded only through concerted action of both employee and employer, any prescribed program must make compliance mandatory for both.

A hearing conservation program will be most effective if a legislature provides by law in general terms that employment be made safe, and if it delegates to a state agency the task of determining what requirements and regulations should be prescribed and the duty of enforcing them.

Simply stated, a hearing conservation program consists of keeping noise away from the employee and keeping the employee away from noise. But there simplicity ends.

It is not enough to extol good or to decry evil. Laws about noise, like all other laws, must provide requirements and procedures which will result in the establishment of necessary standards of conduct. The law must provide for enforcement with penalties for noncompliance to assure that the established standards of conduct will be obeyed.

It is necessary first to determine and decree what noise is harmful. This determination must take into account the complexities of volume, frequency, incidence, duration, distance, susceptibility, and all of their interacting variants.

While those with scientific expertise may contend that their studies have removed the question of what is harmful noise from the area of speculation, the general public cannot be assumed to have a knowledge and understanding of such matters. Thus, harmful noise must be explicitly defined before any rules are drawn as to what may, may not, or must be done about it.

The prime concern is the employee's hearing. Once harmful noise is defined, the next logical step is to prescribe what personal protection shall be afforded the individual employee.

For each employee who may be subjected to harmful noise, there should be, at the outset, an accurate determination and record of his hearing. If he is thereafter exposed to noise which is or may be harmful, subsequent hearing tests should be required with a frequency warranted by the facts.

If progressive hearing loss occurs—despite all measures to prevent it—an employee should be precluded from continuing to work where the exposure to loss occurred.

If an employee will be exposed to harmful noise the employer should be obligated to furnish, and the employee to use, prescribed devices capable of reducing harmful noise exposure to acceptable levels.

Inherent in any effective program is the certainty of its enforcement. There is an understandable but unjustifiable tendency to penalize the errant employer but to excuse the nonconforming employee, usually on the basis that his peculiar personal idiosyncrasies make conformance difficult.

Beyond providing protection to each individual employee exposed to noise, regulations should properly require an employer to take justifiable measures to eliminate, control, modify, or reduce noise. Such regulatory measures should be enunciated only after full, open, factual, and scientific inquiry and should be clear, concise, and unequivocal.

Requirements that machines or other objects be constructed, maintained, or used in ways that avoid emanation of harmful noise must be not only possible to understand but compatible with economic realities. Operational procedures and practices should be held to accepted standards established on a rational foundation.

Generally, because of the major expenses involved architectural requirements can only be implemented on a long-range basis.

The caveat for any regulation should be that its purpose is to preserve hearing, not to impair or destroy essential industrial effort.

Only if the hazard of hearing loss is great and cannot be managed will abatement be justified, and abatement should not be cloaked in the guise of unrealistic regulation.

The rules and regulations should be based on scientific formulae, but so drawn as to be capable of understanding and enforcement by nonscientific persons with a minimum of expert scientific guidance and help. Provision should be made for change if necessary, but change should not be capricious.

Despite all precautions, some industrial loss of hearing must be anticipated. Just as you cannot unspill milk, so you cannot recover hearing lost to acoustic trauma. The problem legally is one of compensating for an irretrievable loss.

Any transient impairment of hearing from exposure to noise is of such short duration as not to merit consideration for indemnification. Thus, compensation, or indemnity, for noise-induced hearing loss pertains only to payments to be made for partial or total permanent loss of hearing.

Like laws regulating exposure to noise, those pertaining to compensation for hearing loss vary widely in the extent to which legislatures, by detailed provisions in the statutes, reserve to themselves or delegate the promulgation of the conditions governing the regulation and determination of the subject matter.

In jurdisdictions in which industrial hearing loss has not become an economic problem the statutes tend to ignore it entirely, leaving its determination and management, if it occurs, to be adjudicated under the general workmen's compensation law of the state.

At the other extreme an explicit and comprehensive law reflects a recognition by the legislature of the problems involved in industrially-induced hearing loss.

But a state legislature, with full appreciation of the problem, may delegate to a competent agency within the state the task of prescribing rules and regulations by which the extent of hearing loss is determined and may also leave to such an agency the power to determine the extent or percentage of industrial disability to be ascribed to such loss.

There has been general acceptance, by statute, regulation, and in practice, of the 1961 AMA formula to measure percentage of hearing impairment, both monaural and binaural, though there are a sufficient number of jurisdictions which impose their own minor variations.

Some jurisdictions make an allowance for presbycusis; others do not.

Some states specify by statute or regulation the benefits for binaural and monaural hearing loss in terms of weeks of benefits to be paid. Others leave the determination of the over-all permanent disability due to hearing loss in an individual case to evidentiary proof, generally predicated on the whole man theory.

Some states treat hearing loss by statute specifically as an occupational disease.

The jurisdictions vary as to the amount to be paid for loss of hearing, but payment is usually commensurate with other relative disability impairments suffered by workmen in the particular jurisdiction, with the general level of benefits depending on the strength of the economy and the interplay of politico-economic forces in the jurisdiction.

A number of statutes provide for and permit collection of benefits for loss of hearing where the employee continues to work, often at the same job, without wage loss.

At least one statute provides that no permanent disability indemnity payments may be collected by an employee who has suffered loss of hearing from exposure to noise until at least six months after he is no longer exposed to noise capable of causing hearing impairment.

Another type of provision precludes payment of permanent disability indemnity until six months after termination of the employment in which the hearing loss was sustained, not merely the termination of exposure to noise.

Permanent disability payments exhibit chameleon qualities when viewed in partisan lights. When there is no demonstrable wage loss, labor contends the payment is for physical injury of the employee and potential rather than actual loss of wages. If the employee can continue to work, management contends that indemnity should not be paid since there is no wage loss to indemnify. If the man cannot continue to work, management tends to ignore his wage loss and to pay him on a limited schedule for prescribed disabilities, but labor insists then that the entire program rests on an adequate wage-replacement concept.

Legislatures over the years have adopted part or all of each theory at different times and under different circumstances as pragmatism has dictated.

Pragmatism dictates that indemnity benefits for permanent disability due to hearing loss not be paid to an employee continuing to work without any present wage loss. Productive industry cannot survive if required simultaneously to pay for work and for the inability to work.

Where permanent disability payments are deferred until the end of a period following last exposure or last employment, adequate statutory provision must be made to assure that justifiable claims will not be barred by lapse of time.

Where such benefits are deferred and not, therefore, paid out prior to death, though the employee has made timely application for them following cessation of his employment, equitable provision should be made for payment to his dependents or to his estate of benefits accrued from cessation of employment to time of death.

One of the problems still unsolved in many jurisdictions concerns assessment of liability between successive employers, or successive insurance carriers, or both, if loss of hearing is due to cumulative exposure over a period of years.

The most expeditious rule is one that holds the last substantial employer liable with some provision for a minimum period of employment, and during such period the right to medical examination and employment termination before liability attaches.

Whether the last employer should be allowed a right of recovery against prior employers to the extent that their employment contributed to the harm and resultant monetary loss is debatable. The turn of the wheel of fortune may distribute losses equitably enough on a mere incidence basis, though an unwary employer could readily be bankrupt.

If an established loss of hearing is only in part due to employment exposure to noise, and otherwise to factors unrelated to employment, a proper apportionment should equitably be made, and industry should be held responsible only for that portion of the hearing loss caused by its environment.

If an employee has sustained part of his loss of hearing in one state and the balance of the loss of hearing in a second state, the only practical rule would hold the last employer responsible, in the new state, after a stated minimum period of employment, during which the right of medical examination and discharge should exist.

To hold litigation procedures to a minimum, provision should be made for competent, qualified, and respected impartial medical examination to determine the degree of hearing impairment in contested cases. The examiner should be acquainted with all of the sophisticated tests necessary to accurately determine hearing loss and should have available to him all necessary facilities.

Control of industrial noise through regulation and imposition of liability will result in an effective industrial hearing conservation program if the regulations prescribed and the liabilities imposed are practical and equitable.

Addendum

1. For an analysis of state laws, see Fox, M. S., Comparative Provisions for occupational hearing loss, *Arch. Otolaryng.* 81, 257 (1965).
2. For a general discussion of the law pertinent to industrial loss of hearing

claims, see Larson's Workmen's Compensation Law, 1A, Sec. 41.40, pp. 622.122-622.133.

3. For the type of statute prescribing in detail the criteria and conditions governing loss of hearing claims, see Vernon's Annotated Missouri Statutes, SEC 287.197 and West's Wisconsin Statutes Annotated, Sec. 102-555.

4. For the type of statute setting forth certain criteria and delegating establishment of other criteria to an administrative agency, see the New York Workmen's Compensation Law, Sec. 49aa-49gg, and the rules of the New York Board pertaining to claims for occupational loss of hearing New York Consolidated Laws Servce, 11A.

5. For a statute defining injury generally without specific reference to impairment of rearing and delegating to an administrative agency the establishment of criteria for determination of permanent disabilities (including loss of hearing), see California Labor Code Sec. 3208 and 4600.

   The California Division of Industrial Accidents has established criteria for permanent disability evaluation in loss of hearing claims in its Schedule for Rating Permanent Disabilities, pp. 3B, 4, and 70.

6. The California Labor Code provides in general terms for safety in employment but delegates establishment of safety regulations to an administrative agency (California Labor Code, Div. 1, Ch. 6, and Div. 5, Part 1, Ch. 1-4. The Standards for Noise Control of the California Division of Safety are a model of thoroughness and simplicity (California Administrative Code, Title 8, Sec. 3870-3872, with Appendix A).

   Because the California Administrative Code is not generally available nationally, these orders are set forth here verbatim:

TITLE 8 DIVISION OF INDUSTRIAL SAFETY 432.123
GENERAL INDUSTRY SAFETY ORDERS

(Register 63, No. 3—2-23-63) Article 55. Standards for Noise Control

GROUP 6.1. NOISE CONTROL SAFETY ORDERS

Article 55. Standards for Noise Control

3870. PURPOSE. Article 55 sets up minimum standards for the control of and exposure to excessive industrial noise in order to contribute to the conservation of employees' hearing.

NOTE: Authority cited for Article 55: Sections 6312, 6500, and 6505, Labor Code.
History: 1. New Article 55 (Sections 3870 through 3872) filed 2-13-63; effective thirtieth day thereafter (Register 63, No. 3).

3871. ENGINEERING CONTROL OF NOISE. Whenever the operations reasonably permit, exposures to excessive noise shall be eliminated or at least reduced by engineering or operational controls.

3872. PERSONAL PROTECTIVE EQUIPMENT. (a) WHEN TO BE WORN. Whenever the exposure to noise equals or exceeds the levels given in Table

I, Appendix A, the employer shall provide and the employees shall use acceptable ear protectors. (For the purpose of these Orders, "acceptable" means acceptable to the Division.)

(b) EDUCATION IN USE OF EQUIPMENT REQUIRED. The employee shall be informed of the locations where the wearing of ear protectors is required, and shall be instructed in the use of such ear protectors.

(c) PROVISION AND CARE OF EQUIPMENT. DUTY OF EMPLOYER AND EMPLOYEE. It shall be the duty of the employer to provide such ear protectors as may be required and to replace them when necessary. It shall be the duty of the employee to properly use such equipment provided for him and to exercise due care to keep same in efficient and sanitary condition.

APPENDIX A

Because of the wide physiological response to noise, compliance with these Orders may not prevent hearing loss to all employees, but should provide an environment where the exposure to noise is controlled to the degree that employment therein is considered reasonably safe.

If an employee is exposed to noise for five or more hours per normal workday, the levels shown in Table I are the levels at and above which the wearing of hearing protectors is mandatory. For employees whose exposure to occupational noise is less than five hours per day, the noise levels may be 3 dB higher for each halving of the exposure time; e.g., for an exposure of 2½ hours, the noise levels encountered may be 3 dB higher in all frequency ranges than the values shown in Table I; if the exposure time is 1¼ hours per day, the noise levels may be 6 dB higher than Table I before the ear protectors must be worn.

The noise levels are to be obtained by sound-measuring equipment having the characteristics outlined by the American Standards Association, Incorporated, or equivalent standards.

432.124 INDUSTRIAL RELATIONS TITLE 8
(Register 63, No. 3—2-23-63)

Table 1

Frequency Band Cycles Per Second	*American Standard Preferred Frequencies for Acoustical Measurements*	*Octave Band Sound-Pressure Level Decibels (re: 0.0002 Dynes/sq cm)*
20- 75	63	110
75- 150	125	102
150- 300	250	97
300- 600	500	95
600- 1,200	1,000	95
1,200- 2,400	2,000	95
2,400- 4,800	4,000	95
4,800-10,000	8,000	95

Control of Industrial Noise Through Personal Protection

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When noise reduction and isolation measures have failed to reduce a noise to levels acceptable in terms of damage risk, the provision of ear protection has to be considered. The object of such protection is to reduce the amount of sound energy transmitted to the inner ear, thus protecting the cochlea. Methods of protection and their associated problems have been described in detail recently by Michael (1965) and by Rice and Coles (1966).

Basic Types of Ear Protectors

Reduction of Transmission by Air Conduction

Earmuffs. These are rigid cups specially designed to cover completely the external ears. Two cups are held in place by an adjustable headband or are mounted in a helmet. Each cup has a soft cushion filled with plastic foam, or a fluid, such as glycerine, to ensure a good fit between the cup and the head. The fluid-filled cushion is called a "fluid seal."

Earplugs. These are available in two general forms: (1) prefabricated earplugs, made of rubber or plastic, and usually supplied in a variety of sizes; and (2) temporary earplugs in the form of a disposable material, such as wax-impregnated cotton or specially fine glass wool described as "glass-down."

Reduction of Transmission by Bone Conduction

Anything which impedes normal sound conduction causes a conductive hearing loss, although the magnitude is limited to about 60 dB; after reduction of intensity by this amount the remaining sound is conducted through the bones of the skull directly to the inner ear, avoiding the ossicular chain. This bone conduction is important in several contexts. It accounts for the shadow audiogram found in patients with severe unilateral deafness, and in clinical diagnosis it means that any hearing loss much greater than 60 dB cannot be wholly conductive. Moreover, in ear protection the maximum amount by which an ear protector can reduce the sound reaching the ear is limited to about 35 dB at a frequency of 250 Hz up to about 60 dB at the higher frequencies; the addition of helmets which seal off the whole head can, however, increase the sound attenuation by another 10 dB, after which conduction of sound by the body as a whole adds a further limitation.

Helmets. Helmets are commonly used to support earmuffs or earphones and cover the bony portion of the head in an attempt to reduce bone-conducted sound. They are particularly suited for use in high noise levels: for communication and for additional safety, such as protection of the eyes and of the head against bumps or missiles, if it is required. With good design and careful fitting of the seal between the edges of the helmet and the skin of the face and neck, a further 5 to 10 dB of sound attenuation can be obtained in addition to that already provided by the earmuffs or earphones within the helmet.

Requirements of Ear Protectors

Noise Reduction

The protector should be chosen to reduce noise to an acceptable level. Earplugs are less effective than earmuffs, though either can be inefficient if incorrectly fitted. In general, earplugs can be used in noise levels below 110 dB, whereas earmuffs are usually sufficient in noise levels up to about 125 dB. Either can be used for even higher noise levels depending on the duration of exposure.

Comfort

The acceptability of an ear protector depends on its comfort. All protectors are uncomfortable if worn for long periods. Usually earplugs are judged less comfortable than earmuffs, despite the latter being heavier, more bulky and liable to cause perspiration.

Speech Communication

The use of an ear protector does not necessarily reduce the ability to communicate (Coles and Rice, 1966). The hearing state of the user, the type of noise, and the type of plug are all contributing factors (Coles and Rice, 1965). It is important to judge each situation on its merits and to select a protector accordingly. Earmuffs can incorporate electronic communication aids and earplugs can be designed to have frequency-selective or amplitude-sensitive properties which help communication in certain circumstances.

Other Requirements

It should be possible to fit and remove the protectors quickly and easily. They should be durable—resistant to perspiration—and nontoxic to the epidermis. The cost of an ear protector should be judged in relation to its expected life and the protection required; the prices range from just under 15 cents to 10 dollars, or to very much more in the case of ear defender communication headsets. The nondisposable protector should be easy to clean, repair, or replace.

Evaluation of Acoustic Properties

The most important consideration in the design of an ear protector is its sound attenuation and, consequently, the sound energy it keeps out of the ear of the average person.

The U.S. Standard (1957) method of measuring the attenuation is widely accepted and involves a free-field binaural threshold shift technique. In this, the threshold of hearing for selected pure tones is measured in a free field using both ears of each of a group of subjects with normal hearing. The thresholds are also measured with each subject wearing the selected ear protectors. The average difference between these two thresholds represents the degree of attenuation attained.

Other subjective techniques of measuring attenuation have sometimes been used. They include loudness-balance techniques and the monaural free-field or earphone threshold shift for pure tones. Selected noise bands can be used in place of pure tones. Objective measurements have also been made in various laboratories using artificial-head or artificial-ear techniques, but they need careful interpretation because subjective methods are, in most respects, more realistic. Another objective method with which the author is, at present, concerned is the use of fresh cadaver ears with a microphone in the roof of the deepest part of the extrenal meatus or replacing the tympanic membrane; this technique should combine the advantages of objectivity with realism and have special advantages for studies of ear protector performance at suprathreshold levels and with impulse noises.

It is also necessary to know how variable the amount of protection may be from individual to individual, even when the plugs are fitted carefully. Ear protectors can be judged for this quality comparing standard deviations (in decibels) of the attenuation determinations at each frequency. The standard deviations include components due to variation in audiometric performance by each subject between test and retest. However, in comparing one ear protector with another, the major differences in standard deviation are attributed to the inherent difficulty in completely occluding all shapes and sizes of ear. In the case of prefabricated earplugs this is particularly difficult when there are only a few sizes available.

Commercially Available Ear Protectors

Earmuffs

The best kind of earmuffs is that which embodies the circumaural fluid-seal principle developed by Shaw and Thiessen (1958). The muff itself is a hard, bulky shell which covers the whole ear, but where it fits the head around the pinna there is a plastic ring containing a fluid, usually glycerine. This conforms to the contours of the head and reduces sound leakage. Figure 1 shows an example of such a muff. Only one size is normally provided, but the length of the headband is adjustable. These earmuffs are close to being the most efficient ear protectors that can be made; adding earplugs beneath properly fitting muffs of this type gives very little increase in sound attenuation (except perhaps at frequencies below 500 Hz, which are usually of less importance for damage risk or speech interference), because their attenuation is limited by bone conduction of the sounds. However, they can be uncomfortable and

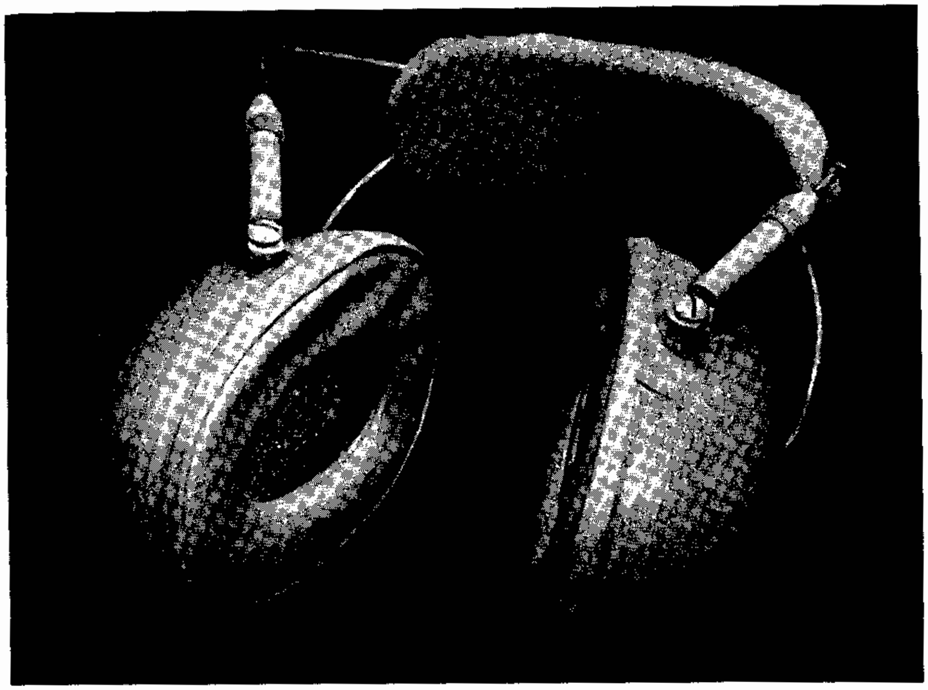

FIGURE 1. Modern type of earmuffs.

bulky and, of necessity, they are tight-fitting. The ears also tend to become hot and to perspire. Despite these disadvantages, they are essential whenever the noise level is very high and the best possible means of ear protection is indicated. Table 1 and Figure 2 show the pure-tone attenuation characteristics.

TABLE 1. Pure-tone attenuation and standard deviation characteristics of ear protectors.

		Frequency (Hz)					
Ear Protector	*Measurement (dB)*	*250*	*500*	*1,000*	*2,000*	*3,000*	*4,000*
Fluid-seal Muffs*	Attenuation	28	38	39	41	44	47
	Standard Deviation	3	4	4	7	4	4
V.51R Plug†	Attenuation	11	13	19	27	30	25
	Standard Deviation	7	9	10	9	6	5
Glass-down‡	Attenuation	11	13	17	29	34	35
	Standard Deviation	5	4	7	6	7	7
Waxed Cotton	Attenuation	10	12	16	27	31	32
	Standard Deviation	9	9	8	11	10	9
Dry Cotton	Attenuation	3	4	8	12	14	12
	Standard Deviation	2	3	3	6	4	4

* Earmuffs shown in Figure 1.
† Similar to those illustrated in Figure 3.
‡ As shown in Figure 4.

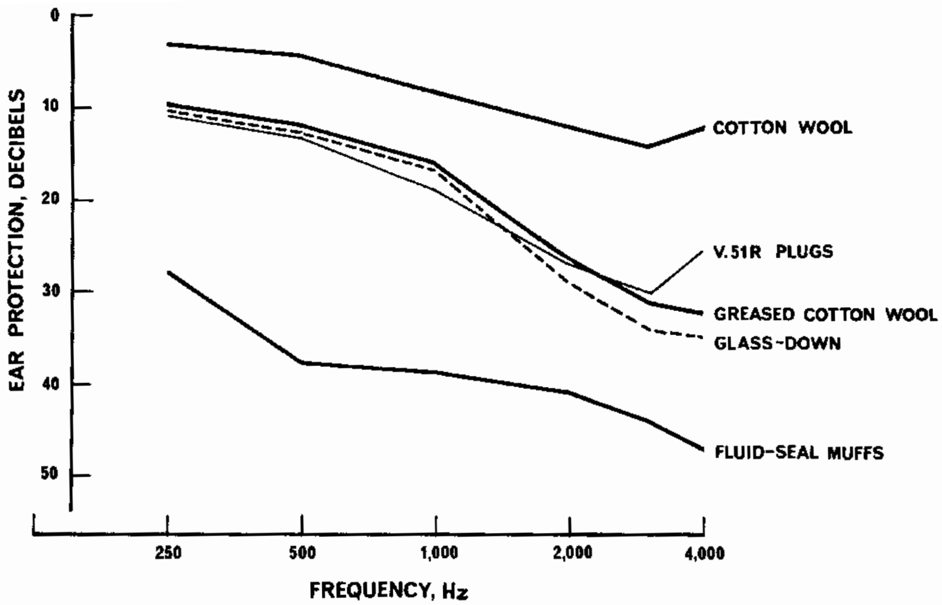

FIGURE 2. Pure-tone attentuation characteristics of some ear protectors (data from Piesse, 1962).

Earplugs

Some of the more commonly used earplugs are described below:

V. 51R Type. One of the most efficient earplugs and certainly the most widely used for personal issue and repeated use is the V. 51R (see Figure 3). It consists of a soft plastic bung carrying a flexible flange that conforms to the shape of the external meatus and makes as complete a seal as possible. The plug was originally produced in five sizes, but several manufacturers (mistakenly, in the author's opinion) have reduced them to three; however, recent demands from users have in some cases resulted in a reversion to five sizes.

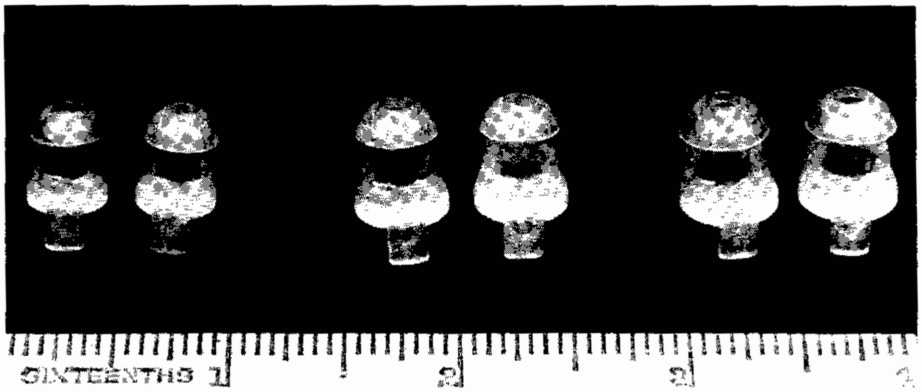

FIGURE 3. The V.51R type of earplug. (Scale in inches.)

The repeated-use type of earplug has a number of disadvantages which limit its practical acceptability. In order to be effective it has to fit tightly and, inevitably, this is uncomfortable. Quite often, because of this and the irregular shape of the ear canals of many persons, an incorrect size of plug is selected, or the plug is not inserted far enough, or a good fit cannot be obtained. Further, the plugs need to be kept clean to minimize the risk of otitis externa, they may easily be lost, and they often tend to harden in time with repeated washing. Table 1 and Figure 2 show the pure-tone attenuation characteristics.

Glass-down. Probably the most practical and acceptable of the disposable forms of earplugs are those made of glass-down. This is a form of glass wool in which the fibers are so fine that they form a material of down-like softness which, as far as it has been possible to ascertain from its extensive use in the United Kingdom and in other countries, is quite harmless even to the delicate skin of the ear canal. To be used effectively, and to avoid pieces of glass-down being left in the meatus, the plug must be folded according to the instructions provided with it—Figure 4 shows how a plug is formed. For

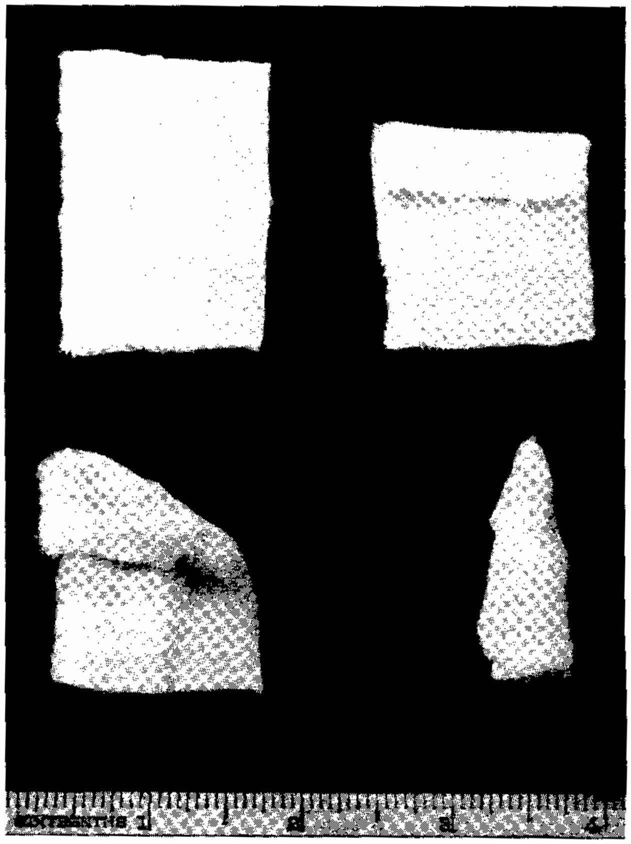

FIGURE 4. Method of forming a glass-down earplug. (Scale in inches.)

industrial use on a large scale, a satisfactory form of dispenser is available. Table 1 and Figure 2 show the pure-tone attenuation characteristics.

Cotton. Cotton earplugs are not advised on account of their inefficiency and the false sense of security which their use engenders. Although the types of cotton supplied more recently for medical purposes appears to have finer fibers than hitherto, they are still found to be rather unsatisfactory. Table 2 shows the pure-tone attenuation characteristics.

If the cotton is mixed with petroleum jelly or paraffin wax it becomes much more efficient. The former is rather messy and not very practical; the latter has to be preformed into earplugs and is available commercially as such. These preformed plugs have a further disadvantage in their lack of elasticity. After awhile, the repeated alterations in the shape of the ear canal caused by jaw movements compress the relatively inelastic plug into a shape that no longer fits tightly and the plug then becomes inefficient.

Taking all factors into consideration, glass-down appears to be the earplug of choice in most noise situations, provided every effort is made to ensure that it is properly formed and inserted. On the other hand, for regular use, simple plastic earplugs such as the V. 51R are considerably less expensive.

TABLE 2. Pure-tone attenuation provided by two forms of cotton.

	Attenuation (dB) at following frequencies (Hz)					
Cotton	*250*	*500*	*1,000*	*2,000*	*4,000*	*8,000*
Old Type: Coarse Fibers	3	3	4	7	10	19
More Recent Type: Finer Fibers	5	9	10	15	16	25

Pure-Tone Attenuation Characteristics and Their Application

Table 1 and Figure 2 show the pure-tone attenuation characteristics of the ear protectors already mentioned. The characteristics of ear protectors have been measured in many laboratories and the results differ considerably. It is not advisable therefore to compare attenuation of ear protectors if the results have been obtained in different laboratories, unless there is a large number of evaluations on a given type of ear protector when the various results may be averaged. The data in Figure 1 have all been obtained in the Commonwealth Acoustic Laboratories (Piesse, 1962) by a free-field binaural threshold shift technique.

It is interesting to note the small standard deviations and the high level of attenuation achieved with fluid-seal ear muffs. The standard deviations of the results from glass-down are also distinctly less than those from V.51R plugs or waxed cotton, although all three show similar mean attenuation values.

For assessing the extent of the auditory hazard when ear protectors are worn, the usual procedure is to subtract the average attenuation from the octave-band noise levels at corresponding frequencies and to compare the noise then reaching the ear with the appropriate damage risk criteria. Figure 5 illustrates such a procedure, though a common alternative is to raise the damage risk criteria by the amount of ear protector attenuation and to compare the octave noise levels with the adjusted criteria.

It should be realized that the attenuation figures, like the criteria, apply only to a certain percentile (50% in the cases of the average attenuation and of most damage risk criteria). For more complete safety the criteria would need lowering by 5 or 10 dB, and the mean attenuation values minus one or two standard deviations would be a more appropriate correction for use of ear protection.

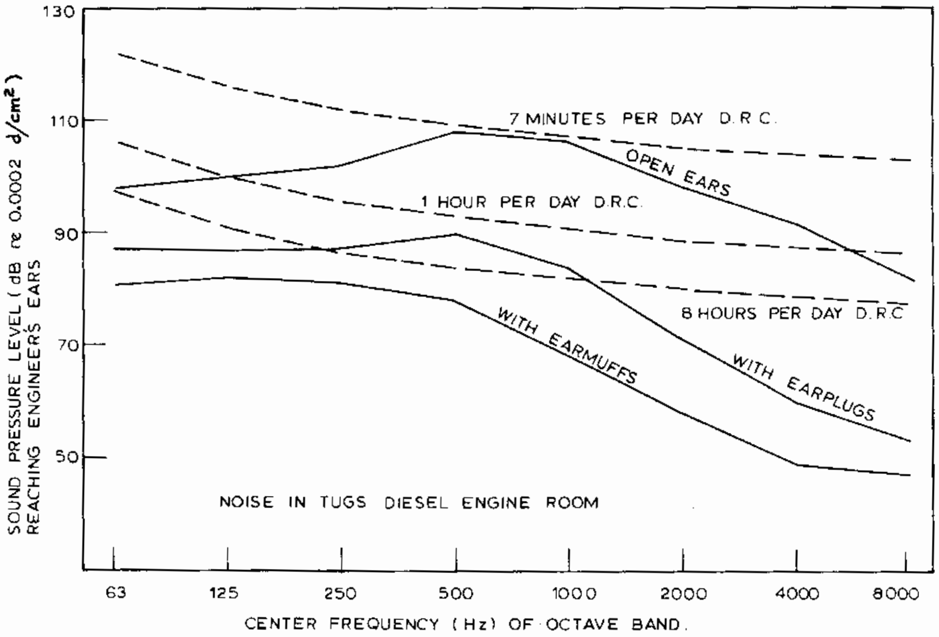

Figure 5. Application of attenuation data to evaluation of noise hazard.

Ear Protectors With Special Characteristics

Frequency-Selective Earplugs

The use of acoustic, low-pass filters in the design of earplugs, and the Selectone-K earplug which incorporates these ideas, have been described by Zwislocki (1951, 1952). Coles and Rice (1966) measured pure-tone and speech attenuation using a monaural earphone threshold shift technique. Table 3 shows these characteristics of the Selectone-K together with those of the V.51R plug; the latter figures are in close agreement with those obtained by Piesse (1962) listed in Table 1.

Table 3. Pure-tone and speech attenuation characteristics of Selectone-K and V.51R earplugs.

	Attenuation (dB) for following frequencies (Hz)						*Attenuation speech (P.B. words, 50% score)*
	500	*1,000*	*2,000*	*3,000*	*4,000*	*6,000*	
Selectone-K	6	10	21	31	31	34	15
V.51R	13	17	26	28	27	25	19.5

From Table 3 one can see that the attenuation provided by the Selectone-K is very small below 2000 Hz. This enables the lower speech frequencies to reach the ear more easily than with the V.51R plug. These characteristics make the Selectone-K more suitable for use when communication is required during periods of relative quiet between bursts of noise. When worn in the presence of a continuous noise, on the other hand, speech communication is impaired more than with the V.51R. This is because low-frequency masking noise is passed in addition to speech.

Another feature of the Selectone-K is that its tiny holes, which give it its low-pass filtering properties, provide a frictional component to impulsive types of noise. In this respect, therefore, the plug can be said to have amplitude-sensitive characteristics also.

Amplitude-Sensitive Earplugs

These plugs have been designed to operate only in the presence of high-intensity noise. This means that little interference with speech would be expected under relatively quiet conditions. The Lee-Sonic Ear Valv, is designed to be self-operating. In the presence of loud impulsive noise a valve in the plug is momentarily thrust into a closed position by means of the energy present in the noise. In high levels of continuous noise the valve is said "to operate under a continuous reciprocating actuation."

Piesse (1962) has measured the pure-tone attenuation characteristics. Since these are relatively poor one would expect the Ear Valv to have advantages over the Selectone-K with respect to speech communication. The efficiency of the Ear Valv in protecting against noise does not appear to have been thoroughly examined. Reports in the literature suggest that amplitude-sensitive earplugs, depending on the action of such a valve, might require extremely high sound-pressure levels to operate (Thiessen, 1962). For example, in rifle firing, when the levels can be above 160 dB. Piesse (1962) and Dickson, Hinchcliffe, and Wheeler (1954) suggest that the plug might not be very efficient in continuous noise. On the other hand, subjective impressions of the Ear Valv and the evident popularity of this earplug in rifle clubs suggest that it may be effective against intermittent impulsive types of noise: it is possible, though, that this may be due to the general sound-attenuating properties of the earplug rather than to operation of the valve.

Effects of Ear Protectors on Speech Communications

In quiet, speech sounds will be heard without degradation by a normal-hearing person wearing ear protectors if they are of sufficient intensity (e.g., conversational voice level). On the other hand, in persons with preexisting, high-tone, perceptive hearing loss their already-reduced ability of speech discrimination, at optimum levels of amplification, is likely to be reduced somewhat further when ear protectors are worn (Coles and Rice, 1965).

But in a background of continuous noise the situation is quite different. At noise levels of about 85 dB SPL, if the voice can be raised sufficiently loudly to be heard at all then ear protectors make little difference to its intelligibility (in a normal-hearing person). This is because the perceived level of both the voice (signal) and the noise is lowered equally by the ear protectors, i.e., the signal-to-noise ratio is unaltered (Figure 6). Further, there is evidence that at levels above about 85 dB the use of ear protectors may actually be beneficial to communication (Kryter, 1946; Michael, 1965). In even more intense noise (110-130 dB), marked improvements in intelligibility of speech in a communi-

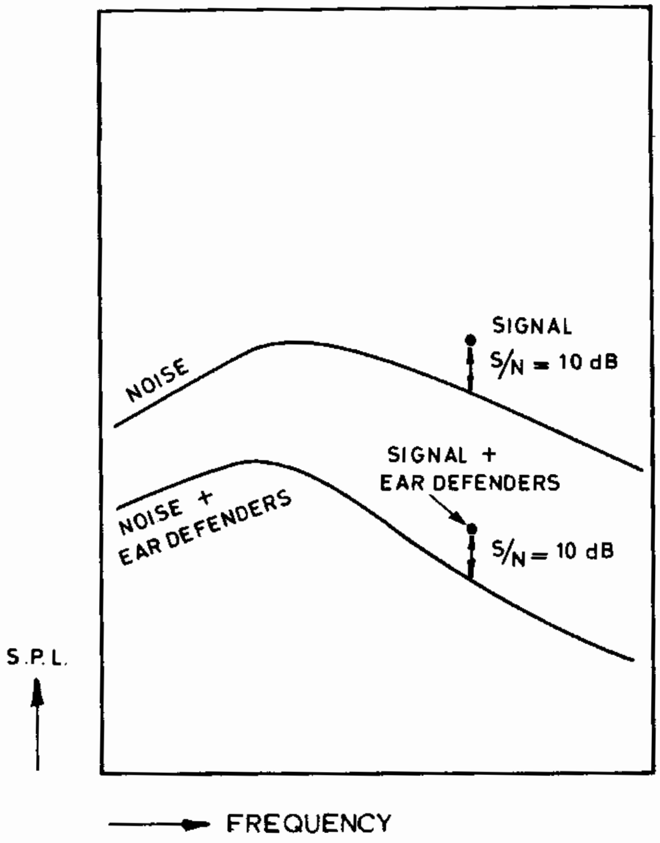

FIGURE 6. Effects of ear protectors on signal detectability in continuous noise.

cation system have been found when earplugs were worn under the earphones (Pollack, 1957). Note that if an efficient sound-attenuating communication headset is used, it is detrimental to communication if an earplug is inserted between the telephone receiver and the eardrum. While the signal from the telephone within the earmuff is attenuated by, say, 20 dB by the earplug the overall attenuation (of the external noise) is only increased by about 5 dB. Thus the effective signal-to-noise ratio is lowered by 15 dB with a very severe effect on signal intelligibility. If an additional earplug is needed, with efficient communication headsets, it is better to use an insert telephone embodied in the earplug; by this means the extra noise attenuation can be achieved without loss of intelligibility. However, with intermittent impulse noises, like gunfire and many industrial processes of percussive type, the peak levels are often far too high for the speech to be audible with or without ear protection, as Figure 7

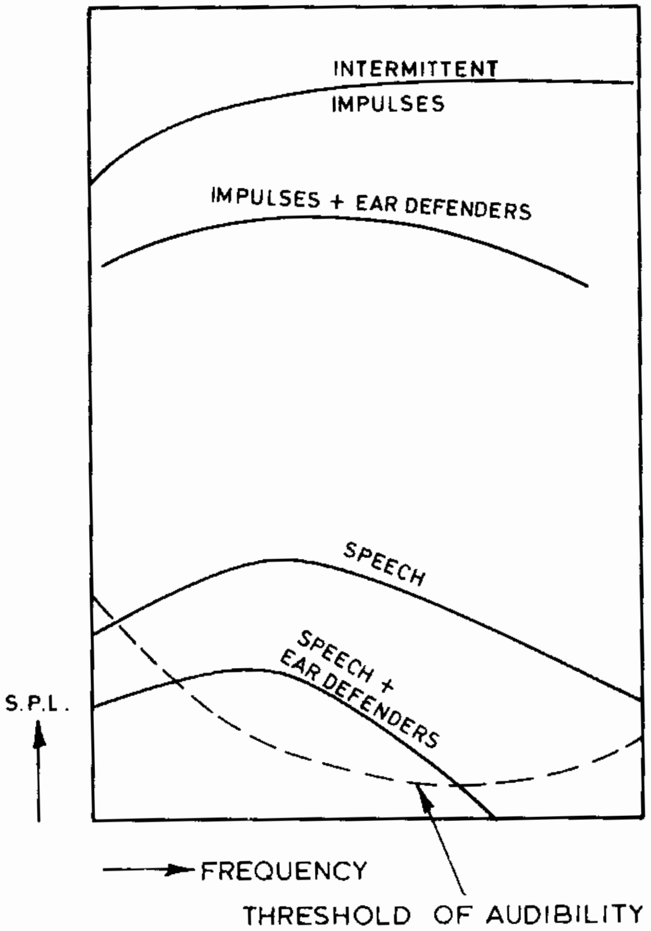

FIGURE 7. Effects of ear protectors on audibility of speech in intermittent impulse noise.

illustrates diagrammatically. In these conditions, speech communication is limited to what is heard in the relatively quiet intervals between the impulses, and its intelligibility in these intervals depends mainly on the factors outlined in the first paragraph of this section.

Another factor reducing the efficiency of speech communication, when it is direct (person-to-person), is the effect of ear protection on the speaker. The speaker's impression of the level of his own voice will be altered little by use of ear protection. This is because the sound of his voice then reaches him by bone conduction and, indeed, its subjective level is enhanced by the occlusion effect caused by ear protectors, particularly earplugs. On the other hand, he matches his voice against a noise which with ear protection is subjectively 20 or 30 dB less intense than it really is. The result is that the speaker wearing ear protectors tends to use insufficient vocal effort to overcome the actual noise of his environment.

The position of persons with impaired hearing when using ear protectors in a noisy environment does not appear to have been studied, but theoretical considerations lead to a conclusion that use of ear protectors may have further disadvantages for these people.

One of the greatest of recent advances in communication in noisy environments has been the embodiment of telephone receivers inside noise-excluding earmuffs. This has a double benefit in practice. While the listener is dependent upon wearing the muffs for markedly improved communication, he is at the same time protected against noise. The headsets may be connected by a cord to a plug-in communication system, which may be portable (Figure 8). In

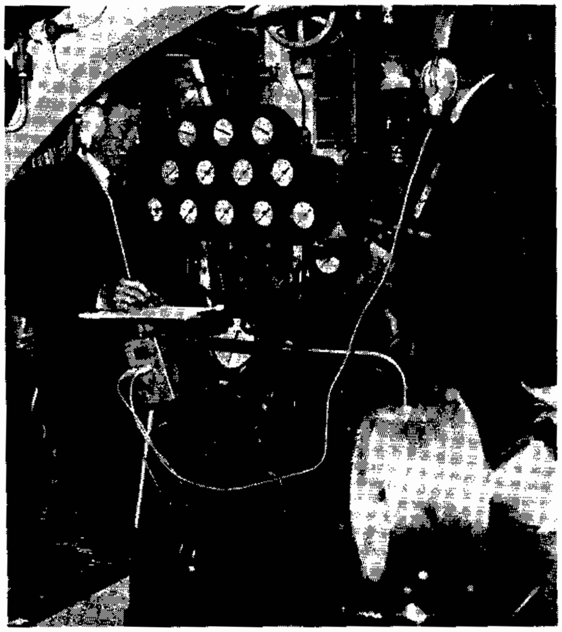

FIGURE 8. Earmuffs containing telephone receivers, with portable communication facility and noise-cancelling microphones.

other cases, magnetic induction-loop receivers may be incorporated and the wearer can then hear instruction anywhere within the area of the magnetic loop without the need of a trailing cord.

Practical Problems with Ear Protectors

Except in the most extreme noises or where communication facilities are embodied, dislike of wearing ear protectors is universal, though varying in degree. Objections are in many cases very reasonable but have to be weighed against the hazard to hearing. In other cases, the objections are less well founded and depend on factors such as self-consciousness, carelessness, bravado, tradition, and unawareness of the dangers. In these cases, the resistance may largely be overcome by discipline, education, and example.

The more valid objections include the following:

Discomfort

Earplugs have to be rather uncomfortably tight in order to be maximally effective, though this seems to be less true of glass-down earplugs than of other types. With a little persistence, the discomfort wears off. Earmuffs tend to make the ears feel hot and sweaty, particularly in warm climates, and their bulk and tightness are apt to cause headaches. Again, persistence is the answer. (For reasons of hygiene and efficiency, each man should have his own personal pair of muffs.)

Ear Infections

In ear infections earplugs are contraindicated. Indeed, external otitis can be caused by earplugs, particularly when repeated-use types are not properly cleaned after use. Earmuffs provide a reasonable alternative in these special cases. Occasionally, sensitization of the skin of the ear canal or around the ear also occurs. In this connection, no particular type of material has yet been shown to be specially at fault.

Difficulty with Communication

In most instances of workers in continuous noise, explanation and demonstration will reduce wearer resistance. In intermittent noise the problem is more difficult. Careful consideration has to be given to the opposing factors of noise hazard without plugs and the risks of impaired communication, which between the noise bursts may be at low intensity and barely audible to unprotected ears. Much of the current research and development on ear protection in the United Kingdom is directed towards a solution of this communication problem with intermittent noise.

Difficulty in Listening to Machinery Sounds or Hearing Warning Signals

In general, the signal-to-noise ratio considerations which govern the hearing of speech against a noisy background are also relevant to the hearing of "indicator sounds." However, on some occasions, use of ear protection may interfere with perception of these sounds, especially in persons with a preexisting, high-tone hearing loss (as may be found in many men working in noisy environments). Most engineers have learned to listen for aberrant sounds, which may indicate a hot bearing, etc., without wearing ear protectors. If, at a later date, they are given ear protectors to wear, they very naturally feel a loss of confidence in their ability to detect and interpret correctly the aberrant sounds. Another factor, affecting even normal-hearing persons, is that indicator sounds become less noticeable when wearing ear protectors. This is because, at the lower intensities then reaching the ear, the loudness of partially noise-masked signals and their ear-catching quality is reduced. Once again, explanation, encouragement, and example are the answers. It may also be helpful to arrange a practical demonstration to show that the sounds do in fact remain audible when ear protectors are worn.

Failure of Ear Protection

Universal use of ear protectors in any given noise-hazardous situation is seldom found, except where the protectors embody communication devices or the noise level is extremely high. Even if protectors are worn, they vary to a greater or lesser extent in efficiency according to the type used (see the standard deviation values in Table 1), to the degree of care in their original fitting and to education in their correct use. These factors of uncertainty, together with variations in exact amounts of noise exposure and the lack of applicability of damage risk criteria to persons who are markedly above average in susceptibility to noise-induced hearing loss, illustrate the need for monitoring audiometry in a hearing conservation program. By means of such audiometric measurements both employer and personnel are safeguarded, because the development of noise-induced hearing loss will detected at an early stage. In addition, by preemployment audiometric testing, the employer is protected against subsequent claims for deafness by personnel who may have had hearing impairment prior to their present employment.

References

COLES, R. R. A., and RICE, C. G., Earplugs and impaired hearing. *J. Sound Vib.*, **3**, 521-523 (1965).

COLES, R. R. A., and RICE, C. G., Speech communication effects and temporary threshold shift reduction provided by V.51R and Selectone-K earplugs under conditions of high intensity impulsive noise. *J. Sound Vib.*, **4**, 156-171 (1966).

DICKSON, E. D. D., HINCHCLIFFE, R., and WHEELER, L. J., Ear defenders: An investigation into their attenuating properties. London: *Flying Personn. Res. Commit., Rep. No. 884, Minist. Def. (Air)* (1954).

KRYTER, K. D., Effects of ear protective devices on the intelligibility of speech in noise. *J. Acoust. Soc. Amer.*, **18**, 413-417 (1946).

MICHAEL, P. L., Ear protectors: Their usefulness and limitations. *Arch. Environm. Hlth*, **10**, 612-618 (1965).

PIESSE, R. A., Ear protectors. Sydney, Australia: *Commonw. Acoust. Lab., Rep. No. 21* (1962).

Pollack, I., Speech communications at high noise levels: The roles of a noise-operated automatic gain control system and hearing protection. *J. Acoust. Soc. Amer.*, **29,** 1324-1327 (1957).

Rice, C. G., and Coles, R. R. A., Design factors and use of ear protection. *Brit. J. industr. Med.*, **23,** 194-203 (1966).

Shaw, E. A. G., and Thiessen, G. J., Improved cushion for ear defenders. *J. Acoust. Soc. Amer.*, **30,** 24-36 (1958).

Thiessen, G. J., Reduction of noise at the listener's ear. In *Control of Noise*. London: H. M. Stationery Office, 153-163 (1962).

Zwislocki, J., Acoustic filters as ear defenders. *J. Acoust, Soc. Amer.*, **23,** 36-40 (1951).

Zwislocki, J., New types of ear protectors. *J. Acoust. Soc. Amer.*, **24,** 762-764 (1952).

Summary

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Our speakers have covered the topic "Industrial Noise and the Worker" very well in the short time allotted. Obviously, an entire session could have been devoted to any one of these complex topics.

Miller has pointed out that overexposure to high-level noise has long been known to cause hearing loss. In fact, there are references that date back as early as 1880 (Moos, 1880) on this subject. It might be expected then that complete hearing conservation criteria should have been well defined by this time, but this has not been done. Prior to 1948, apathy was a major reason for the lack of progress; during this period hearing loss was not a significant factor in workman's compensation. Regulations and compensation claims stimulated awareness of the problem after 1948, but the lack of data handicapped early attempts to establish criteria. Even now there are not adequate data to establish hearing conservation criteria for many of the more complex noise exposure patterns. Miller has explained that laboratory-induced temporary threshold shift (TTS) has been used as basic data in many proposed criteria; although this is the best approach available for many noise exposure patterns, some uncertainty exists as to the validity of this procedure in establishing hearing conservation criteria.

One of the main reasons for the lack of data relating noise and hearing levels is the extreme difficulty in determining a man's noise exposure history, on and off the job, over the many years that hearing may be damaged. Another reason is that the problem has been unrecognized or perhaps ignored in many instances, and no attempt has been made to define the problem. There is also the problem of inaccurate measurement data. Much effort is being wasted in industrial audiometric programs because the audiometers are not accurate, the test room is too noisy, or the technician is improperly trained. In many cases, hearing thresholds are measured a short time after the man has been exposed to high-level noise and temporary threshold shift effects prevent accurate measurements.

A considerable amount of effort is wasted on hearing conservation programs because no action is taken after hearing and noise measurement data are collected. It is difficult to understand why industries which are very cost conscious would spend thousands of dollars on hearing and noise measurements that are filed and never used, particularly because many of the records with TTS effects would do them more harm than good if subpoenaed.

Miller has also mentioned that social and legal considerations are important in the formation of hearing conservation criteria. Basic definitions of normal hearing levels and hearing damage must be made, and they vary widely depending on the point of view. Unfortunately, these considerations are not emphasized, and the criteria are often used without due consideration of these definitions.

In addition the percentage of persons to be protected must be established. There has been some reluctance to emphasize the fact that some of the proposed criteria do not protect 100% of the population. Everybody agrees that 100% of the population should be protected wherever possible; however, depending upon the definitions for normal hearing and hearing loss, it may not be possible to prevent some loss in the most susceptible unless a very large percentage of employees wear ear protection. This may include office workers in some instances.

The difficulty in establishing a successful hearing conservation program is directly related to the number of persons to be covered, and this number will rise rapidly as the criteria are lowered to include all susceptible persons. Further, Coles has pointed out that wearing ear protection will generally increase the difficulty in speech communication as the noise background levels are lowered and, as a result, the universal use of ear protectors is seldom found except where protectors embody communication devices or where noise levels are extremely high. Thus, perhaps 90% of the effort put into a hearing conservation program would be required to protect 5 to 10% of the most susceptible individuals.

The significant increase in difficulty and expense necessary for protecting the most susceptible individuals has in some instances prevented the establishment of any effective program. For example, one large company in the east had, for several years, a very effective hearing conservation program based on the mandatory use of ear protection equipment in areas where noise levels were above 90 dB re 0.0002 microbar in octave bands; but recently, when this limit was lowered to 85 dB, compliance with the program became very poor, and the complete program has become ineffective. The overwhelming number of persons to be covered by the lower level, and the fact that ear protectors are more bothersome at the lower levels are blamed for the overall failure of the program. Workers also learned through an education program that relatively few persons would suffer hearing damage if they didn't wear protectors at lower noise levels, and each thought himself one of those who would not be affected. The conclusion might be reached that more hearing would be protected, at least at the beginning of a program, with a compromise level that would protect a large majority of persons exposed.

After considering the many variables that are involved in establishing a hearing conservation criterion, it is indeed pleasant to learn from Pickett that the effect of noise on speech communication can be predicted with some certainty, at least for simple cases. Unfortunately, many industrial situations are complicated somewhat by complex noise spectra and by workers who have various kinds of hearing losses.

Engineering principles of noise control are also defined with much more certainty that hearing conservation criteria. Botsford and Coles have mentioned that engineering control of noise is the preferred method for hazard control wherever practical. Certainly, it is simpler to deal with machines than with people in many cases; however, there has been a considerable amount of money wasted on engineering control procedures. Such procedures are most important in the design of new equipment or installations where considerable improvements can be made as Botsford described. Many successful applications of engineeirng control can be cited for existing installations, but all too often thousands of dollars are spent on engineering procedures and in the end, individual protective equipment must still be used. For example, it does very little good to reduce noise exposure by 8 dB if a 15 dB reduction is required to meet the hearing conservation criteria. A good ear protector program should provide adequate protection in either case.

Ear protector attenuation data are often confusing to those trying to make a choice between different protectors because the attenuation values for the same protector may vary significantly from one evaluation to another. Coles has made the important point that attenuation data from different laboratories cannot be compared in many cases. Different test conditions and techniques can change the results significantly even though USA Standards Institute Method (1957) is reported to be followed. For example, the decision to use maximum or average attenuation figures can change low frequency values by more than 10 dB. The method for fitting and inserting insert-type protectors are also important factors.

The USA Standards Institute Method for evaluating ear protectors is time consuming and has serious limitations, as Coles has explained. However, other methods have been used for evaluating ear protectors and none has shown an overall advantage over the standard method. The Institute of Electrical and Electronics Engineers has had a committee charged with the responsibility of finding the best artificial-head configuration for evaluating ear protectors for two years, and we have hopes of making a recommendation soon. It is not likely that an artificial-head method will ever be complete in itself because some subjective tests will probably be needed, at least for fitting. However, the artificial-head method is fast; and it should provide a convenient means of performance comparison within various classes of protectors. Coles' findings from his tests with fresh cadavers should provide valuable information on this subject.

Leonard has pointed out that it is logical first to consider prevention of noise-induced hearing loss, and later to consider compensation for any losses that are sustained. Leonard has stated that hearing loss can be precluded only through concerted action of both the employer and employee; and that any prescribed program must make compliance mandatory for both. This is certainly a fair way to approach this problem. All too often the fact that ear protection equipment was provided has been ignored in compensation settlements even though the losses could have been prevented if the protective equipment were worn properly. The employer must assume the responsibilities of educating the employee regarding the dangers faced and the use of protective equipment; however, he is in a poor position to enforce the wearing of protective equipment in very large groups without a law to provide penalties for noncompliance of the employee. Even with such a law, and constant policing to be sure the protectors are being worn, it is impossible to be sure that an employee is getting adequate protection, because he may be wearing the protectors improperly. Certainly, a clearly written and well-defined law should be helpful if it is based on practical criteria; however, legal enforcement by itself will not guarantee a successful hearing conservation program. On the basis of past experience, a successful program cannot be developed unless the need for such a program is well recognized by both the employer and the employee. Another important ingredient in almost all successful programs has been a dedicated individual or group of individuals who work full-time to provide the necessary indoctrination and continuing education program.

References

MOOS, S., *Arch. Otolaryng.*, **9**, 319 (1880).

United States of America Standards Institute, Method for the measurement of the real-ear attenuation of ear protectors at threshold. Z24.22 (1957).

Panel III

Noise in the Community

Opening Remarks

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Our conference, to this point, has dealt with man's individual reaction to noise, the effects of noise on speech communication, the effects of noise on hearing, and the physiological and psychological effects of noise. The second session concentrated on noise in industry and the effects of noise on the worker. The following sessions will concentrate on noise in the community. This session will open the review of this problem area with four papers.

Our first paper covers what noise does with respect to speech communication in the community. The second paper deals with community noise sources: how we measure and describe the noise environment. The third paper discusses how the community reacts to noise as observed by scientific methods. And the fourth paper will tell us what the community and the citizen really think about noise.

I think it is important to note that our program jumps from man's individual reactions to noise to the more or less statistical treatment of the community reaction to noise. I personally think this jump constitutes the biggest gap in our knowledge about noise and man. This has already been stressed in the Keynote Address by William H. Stewart, and also by Walter A. Rosenblith, but it is important to restate it again: We know very little about the integrated response of man to noise--what noise and living in a noisy environment really does to the whole man. What are the long time effects on his health and well being? How do they affect man, and how do they change him? These questions were not discussed in connection with industrial noise, although investigations such as the one by Gerd Jansen give us significant indications that many important and completely unsolved problems wait for us in this area. It is still more important to state that very little research is being conducted or planned in this area, which is probably the most important question in connection with the public health aspects of ever-increasing noise levels. The amount of research, which has been done and is being proposed to refine our answers to nicely separated, "clean" problems in the individual disciplines, is confronted by a void of research on the problem of what the total effects of noise on the total man are, undivided and undissected by individual subresponses. In one of the later papers by Dorn McGrath we read that in 1926 the U.S. Supreme Court referred to zoning as a means "to decrease noise and other conditions which produce nervous disorders." As much as we all personally subscribe to this point of view, it is evident that we have little hard data to support such statements. And, unfortunately, little long-range research—longitudinal studies following the effect of noise on one individual over many years—is going on to provide us with such data.

Rosenblith stated that in this area it gets harder and harder to design meaningful and good laboratory experiments. If this is the case, and I fully agree that it is, we must draw the consequences and do the experiments where the problem is—in the community and in the real environment. This might mean some change in the scientific methods now being used, but there is no question that this is required to solve the problem. It is obvious that this is a very difficult and very complex task, and that it means fostering and supporting broad-based interdisciplinary team studies over long time periods. But unless such a program is launched, it is not hard to foresee that no matter how brilliant and successful the studies by the individual disciplines are, they will not add up to the progress required to solve the overall problem at hand.

After this remark on the evident gap in our program and in our knowledge let me turn to the session at hand, noise in the community. If you deal with noise in the community, you more or less neglect the individual per se; you deal with the individual as a statistical unit. Although I am sure that community noise problems existed since communities evolved, it was—in contrast to the individual effects of noise—not until after World War II that this larger problem was attacked by scientific efforts. The reason for this was probably not that the noise environments in the cities grew so much worse at this time, but rather that the population shift towards an urbanized society and the growing air transportation industry exposed more people to unpleasant noise environments.

Noise in the community has two basic aspects. The one is the effect of noise on the community. The second one is what the community does about the noise.

Figure 1 illustrates the effect of noise on the community. It indicates how we have various individual noise sources in the community; indoor noise, from your own household, other households, ground traffic, aircraft noise, and what is lumped together here as stationary noise sources. All these add up together to the complex problem of community noise, and one of our papers will deal with this problem: how do we describe this overall complex "community noise source" or noise environment?

Community noise acts on individuals who react consciously and unconsciously to this noise. As mentioned before, I think we have considerable knowledge about man's individual responses and we have some preliminary insight into what his immediate response is. However, we know practically nothing about how the physiological and psychological effects change with time, what the long time effects are and how much man adapts to the environment. We know little how big a share noise contributes to the total daily living stress of our modern society. Out of the various individual responses, as Paul Borsky will

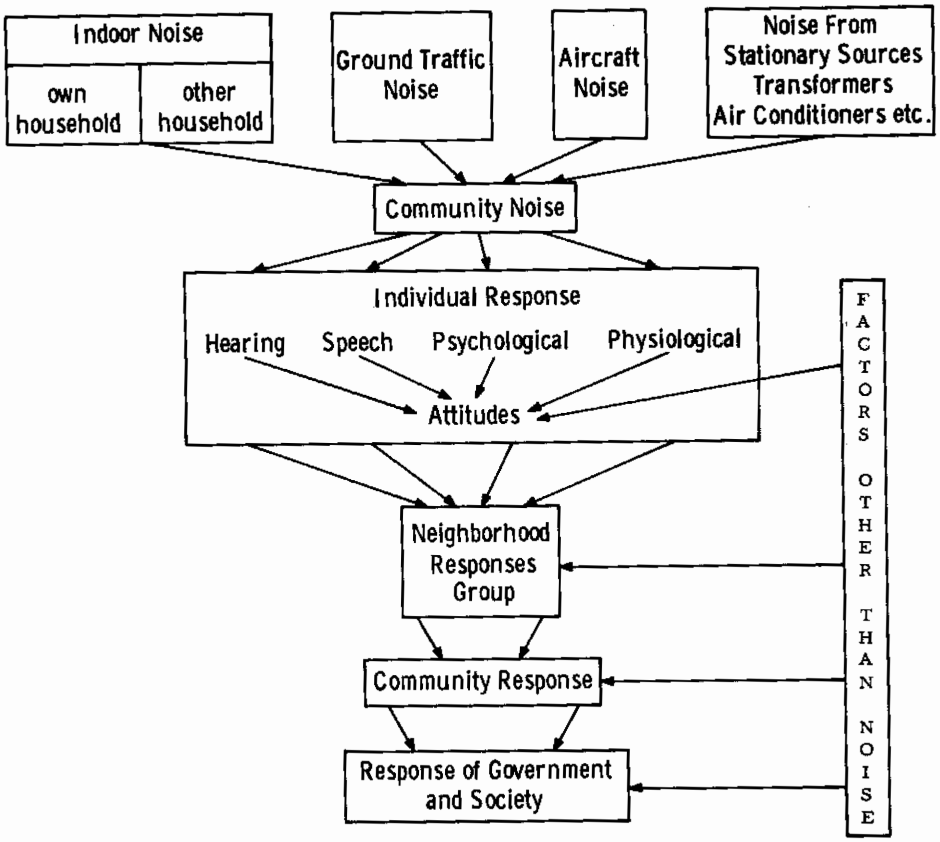

FIGURE 1. Action of noise on the community.

explain to us, the neighborhood or group response is formed. One of the results of the community studies was that the group, or neighborhood, is the unit where the actual opinion-forming takes place. Out of these group responses the community response is formed and out of these the response of the government and of society. It is important to note that individual, neighborhood, community, and government responses are subject to other outside influences directly, indirectly, and not all connected to the noise which affects the formation of the overall attitude toward the noise and the final response. This is indicated by the influences "Factors other than noise" in Figure 1.

The action of noise on the community, as illustrated in Figure 1, is not a passive system. It is important to realize that this is a feedback system and that each of the sociological levels indicated has the possibility to influence noise and strike back at it. After all, we like to think that by and large we have the environment we deserve or want, and if we want to change the environment in which we live, we have to do something about it.

Now, what are the responsibilities for action in this area? I think this has been the cause of misunderstanding and discussion over many years. I divide the action of the community on noise into two areas of responsibility: the scientific-technical and the administrative-governmental areas. The responsibility of science and technology can be summarized as follows: We have to characterize and measure community noise; we have to give scientific data to relate community noise to community reaction; we have to agree on uniform measurement and assessment procedures, and we have to provide, as James H. Botsford stressed, the technology for noise control. Finally, we have to evaluate the control possibilities and give alternative plans, desired environments versus costs and goals.

The community, the government, and society have the responsibility to select realistic and generally acceptable solutions from the scientifically stated possibilities; they have to decide on the corresponding noise exposure criteria; finally they have to work towards the realization of solutions by legislations, codes and standards, by public and technical education, by research support, and, last but not least, by enforcement. One of the most important points here is the second one: the decision of what noise exposure criteria one should and can select in public life is not a scientific one, but is an adminsistrative one or one which has to be made by the society as such.

It is important to realize what problems can be solved by more research and what problems can be solved by action only. No research will give a final answer to the question of what environmental exposures should be permissible. This is a question of the goal selected by the community, the state, and society: What environment do we want and what environment are we willing to pay for? No doubt, the technical information on which to base such decisions has still many gaps and 10 years from now we will have more data to describe the alternatives in quantitative terms. However, there is no question that already today we have enough information to make intelligent decisions. It is obvious that in spite of many unsolved technical problems the main challenge and problem at this point in time in noise control history is primarily in the realm of community, government, and society. How can we make optimum use of the knowledge we have?

I would like to conclude my remarks with a quote from the excellent article by Broadbent, in the *Handbook of Noise Control,* in which he deals with the effect of noise on behavior, and states the following:

> Much of our civilization rests on the assumption that it is worth doing more to the environment than merely securing survival. Reduction of noise or the pursuit of happiness is not necessarily an ignoble end.

References

BROADBENT, D. E., Effects of noise on behavior. In C. M. Harris (Ed.), *Handbook of Noise Control.* New York: McGraw-Hill (1957).

Speech Interference From Community Noise

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Are the techniques that have been developed for evaluating speech communication systems also suitable for evaluating speech interference resulting from community noise? To consider this question it is necessary to review, briefly, the philosophy underlying these techniques.

A basic method of evaluating speech interference is that of intelligibility testing. Unfortunately, different methods of measuring intelligibility give rise to different intelligibility scores. The procedures are also laborious and time consuming.

It would obviously be very convenient to be able to relate the various types of intelligibility measurement to a common base. Even more useful would be the situation in which this common measure reflects some physical property of the speech stimulus and hence could be measured or computed directly. Not surprisingly, this perfect situation does not exist. However, we can use approximate methods which for many practical situations yield satisfactory solutions.

The development of approximate procedures for predicting speech intelligibility from physical measures of speech and noise has one further objective. As Henning von Gierke pointed out in his introductory remarks, the scientific community has a responsibility to provide uniform assessment procedures. Since it is not always practical or possible to carry out intelligibility tests there is indeed a need for a simple, well-defined physical index which can be used as an approximate predictor of speech intelligibility. Two such indices, the Articulation Index (AI) and the Speech Interference Level (SIL), will be considered in this talk with particular reference to their applicability to community noise.

The more sophisticated of these two measures is the Articulation Index (AI). The AI is computed in the following way. The speech spectrum is broken up into 20 bands, each of which makes an equal contribution to intelligibility. The speech-to-noise ratio plus 12 dB[1] is computed for each band, with a maximum allowable value of 30 dB and a minimum allowable value of 0 dB for each band. The AI is the sum of the adjusted speech-to-noise

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[1] The 12 dB adjustment is discussed shortly.

ratios (in dB) in the 20 bands divided by a normalizing factor of 600. Some adjustments are necessary for noise of high intensity or having a very steep rate of attenuation in the frequency spectrum. Details of these adjustments are given by Kryter (1962a).

Figure 1 shows measured intelligibility scores plotted against the AI. Note that the curves are highly dependent on the type of test material and method of testing. Thus, for example, with an AI of 0.4 an intelligibility of nearly 100% may be expected using a limited vocabulary of 32 PB words, whereas if the vocabulary consists of 1000 PB words the intelligibility score may be as low as 60%. In general, the fewer the number of constraints (e.g., contextual, limited vocabulary) the lower the intelligibility score. It is also important to note that the curves shown in Figure 1 may also vary slightly depending on the listeners tested. For well-trained listeners, the differences between curves for the same experimental conditions are relatively small.

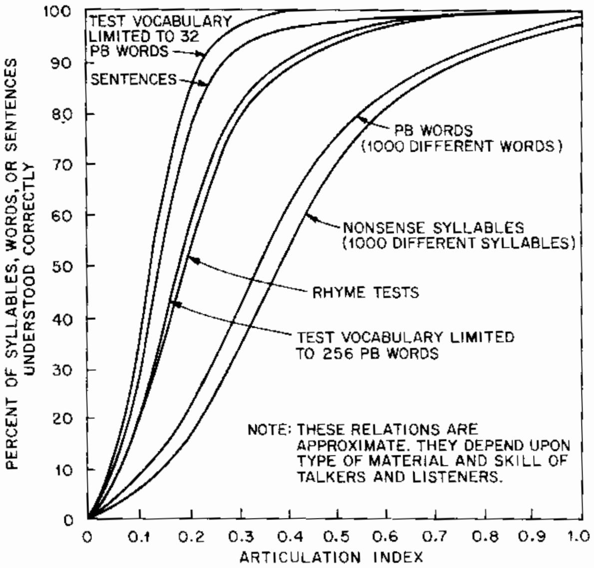

FIGURE 1. Relation between AI and various measures of speech intelligibility (after Kryter, 1962a).

Several basic assumptions underlie the concept of the AI. First, it is assumed that the speech spectrum can be broken up into 20 contiguous frequency bands each of which makes an equal and independent contribution to intelligibility. Within each band the intensity levels of the speech (measured over 1/8-sec intervals) vary over a range of roughly 30 dB and the cumulative distribution of levels on a dB scale is approximately linear (French and Steinberg, 1947; Beranek, 1947). A second basic assumption is that if a portion of the speech over this 30 dB range is masked by noise, then the contribution to intelligibility for that band is reduced proportionately. Since the critical speech-to-noise ratio at which the speech in any one band is completely masked is −12 dB, it is convenient for computational purposes to raise the rms speech spectrum by 12 dB and to define the contribution to the AI for each band as the adjusted speech-to-noise ratio over the range from 0 to 30 dB. The raised spectrum is known as the spectrum of speech peaks contributing to intelligibility (Kryter, 1962a). Thus, for example, if the rms speech-to-noise ratio in a given band is 2 dB then the adjusted speech-to-noise ratio (for speech peaks) is 14 dB and the contribution to the AI for that band is 14/30 of its maximum contribution. Since the maximum possible contribution to the AI for each band is 1/20, the contribution to the AI for the band in question is $1/20 \times 14/30$, or 0.0233.

The preceding two assumptions are reflected in the third and most important assumption which states that percent intelligibility, measured according to any of the standard procedures, is a single-valued, monotonic function of the AI. Empirical evidence in support of this assumption has been obtained by Beranek (1947) and Kryter (1962b), among others, for a wide range of experimental conditions. Predictions of relative intelligibility based on this scheme are, of course, far from perfect, as pointed out by Licklider (1959), and the essentially approximate nature of the AI procedure should not be overlooked.

As an approximate predictor of relative intelligibility, the AI has been found to yield fairly good results when speech has not been subject to nonlinear distortions or severe filtering and when noise is additive, has a smooth spectrum, and is continuous in time. The relative accuracy of the AI procedure for speech interference of this type is perhaps a reflection of the history of the AI since the concept of predicting relative intelligibility from a single index was developed after considerable experimentation on the masking of band-limited speech by continuous, additive noise. Unfortunately, not all types of speech interference are of such a simple nature. Certain types of distortion, however, may be accounted for approximately by second-order adjustments to the AI. In his recent paper on the computation of the AI, Kryter (1962a) provides adjustments for such factors as peak clipping, periodic interruptions of noise, variations in vocal effort, and certain types of reverberation.

Here are factors not accounted for adequately by AI:

(a) Irregular changes in the spectrum of speech or noise, i.e., when the spectrum goes through a series of peaks and valleys, the slopes of which, on average, exceed about 18 dB per octave.

(b) Various types of distortion such as frequency shifting, asymmetrical peak-clipping, and those types of distortion peculiar to vocoder and digital systems. It is also not known how various combinations of distortions affect the validity of the AI (e.g., peak clipping plus reverberation plus periodic interruptions). Similarly, it is not known how well the AI predicts the effects of mixing the speech signal directly from a talker with an amplified version of that signal from a loudspeaker. Finally, it should be noted that the AI procedure has been designed primarily for male speech and the technique has been validated principally against intelligibility tests involving male talkers.

As pointed out at the start of this talk, the AI was devised primarily for evaluating speech communication systems. Direct person-to-person communication is also covered by this technique since, in this case, the communication system consists of the airpath from the talker's lips to the listener's ears. There are, nevertheless, important considerations which distinguish speech interference in the community from that arising with regular speech transmission systems. For example, in many communication systems (excluding specialized binaural or stereophonic systems) both the speech and the interfering noise come from the same physical location. Typically, the speech and noise both emanate from the same loudspeaker or earphone. In the community situation, however, it frequently arises that the speech and noise sources occupy separate spatial locations. As a rule, separating the speech and noise sources tends to enhance intelligibility. The improvement can be quite striking and in certain experiments (Kock, 1950) improvements of as much as 12 dB have been observed. An "improvement of 12 dB" means that, by physically separating the noise and speech sources, the noise level can be increased by 12 dB before the same degree of interference with speech is obtained.

Unfortunately, the gain in intelligibility obtained by physically separating the speech and noise sources depends in a rather complicated way on how the sources are separated and the degree of interference between the speech and noise. At least one attempt has been made at providing quantitative predictions of the gain in intelligibility under different binaural conditons (Levitt and Rabiner, 1967). The technique takes account of the binaural processing by an adjustment to the effective signal-to-noise ratio in each of the 20 frequency bands used in computing the AI. An important prediction based on this technique, which also has found experimental support, is that the largest binaural improvement for flat-spectrum noise occurs at low signal-to-noise ratios and is confined to the low-frequency region of the spectrum. Apart from the improvement in intelligibility resulting from the binaural processing there are additional factors that need to be quantified in going from the binaural to the free-space listening situation. Head movements and head-shadowing effects obviously play an important role. Carhart (1965), for example, has obtained improvements of as much as 16 dB depending on how the head is placed in relation to speech and noise sources.

One other condition which may be fairly typical of the community situation is that of several different noise sources in separate locations. Although there are not many experimental data on this problem, there is at least some evidence to indicate that if the noise sources are separate from each other they tend to interfere more than if they occupy the same location. Treisman (1964), for example, has shown that if a subject is required to listen to one of three speech messages, then the two interfering messages have more effect if they appear to come from separate locations rather than from a single source. The efficiency of selective listening is thus highly dependent on the number of separate locations occupied by the interfering messages.

The preceding experiment also illustrates one further possibility in considering community noise, namely, that noise may consist of other speech sounds. If the interfering sound consists of a babble of several equally loud voices, all emanating from roughly the same location as the desired speech message, then the use of the AI appears to be acceptable (i.e., the babble of voices approximates a continuous noise). It is not clear, however, how the AI should be applied if the noise consists of only one or two voices, or if the interfering voices are spatially separate.

The prediction of relative intelligibility for communication channels is, of course, a more general problem than that of predicting speech interference from noise alone. The speech communication channel may involve distortions of the speech signal as well as the addition of noise. The AI, however, was developed to handle the more general case and it may be worth considering whether some practical simplification or approximation to the AI can be derived. Also, the relative precision required for comparing several communication channels may be greater than that necessary for many noise evaluation situations in which only a very rough prediction of speech interference is required.

A good candidate for an approximate indicator of speech interference is the Speech Interference Level (SIL). The SIL is defined as the arithmetic average of the noise levels (in dB) in three contiguous octave bands. Originally the three octave bands covering the range from 600 to 4800 Hz were used, but it has recently been proposed by John Webster that the three bands centered on 500, 1000, and 2000 Hz, respectively, be used.

In his talk earlier in this conference, Webster reported experimental data showing that for typical shipboard noises, predictions based on the SIL are almost as good as those based on the more complicated AI. Apart from its usefulness as an approximation to the AI, the SIL may also be used as a rough guide in establishing suitable levels of acceptability for environmental noise. Some typical values illustrating the relationship between SIL and interference with voiced communication are as follows:

For an SIL of 45 dB, relaxed conversation can be carried out in a normal voice at distances of up to 10 feet.

For an SIL of 55 dB, continuous communication can be carried out in a normal voice at a distance of 3 feet.

For an SIL of 65 dB, intermittent communication can be carried out in a raised voice at a distance of 2 feet.

For an SIL of 75 dB, minimal communication can be maintained (e.g., danger signals, restricted vocabulary) in a very loud voice at a distance of 1 foot.

The preceding values have been extracted from the *Handbook of Acoustic Noise Control,* by W. A. Rosenblith, K. N. Stevens, et al. (1953). The data are based on the earlier definition of the SIL using the three octave bands covering the range from 600 to 4800 Hz.

Detailed information on acceptable criteria for speech interference in terms of the SIL (both old and new definitions) was presented by John Webster. Rather than repeat this information, I would prefer to discuss some of the precautions that are necessary in interpreting such data. Firstly, all the shortcomings pertaining to the AI concept similarly apply here: i.e., the noise is assumed to have a relatively smooth spectrum and be continuous in time. In addition it also assumed that the noise has no substantial energy outside the measured frequency range (e.g., below 600 Hz or above 4800 Hz). Secondly, the curves are based on average data and hence for some subjects the noise interference will be greater than predicted, whereas for others the interference will be less. Of greater importance, however, is that the human population is not homogenous and that there may be large groups of people for whom, perhaps as a result of training or adaptation, the interfering effect of the noise or the ability to communicate in noise is very different from the rest of the population.

One variable that has not yet been discussed, but may play a crucial role in setting criteria of acceptability, is the length of time that the noise is present and the frequency of occurrence. Thus, for example, an intense noise occurring only once in a while may result in less overall interference than a less intense noise occurring at frequent intervals. A good illustration of such a situation (based on an example given by Ira Hirsh) is that of a schoolroom that is relatively close to a noise source severe enough to mask speech communication almost completely. If the noise occurs for a few minutes only, once or twice a day, then the school may still be able to function adequately. If, however, the noise occurs repeatedly during the day, even if at a lower level, then the overall interference due to the noise may be quite substantial.

Thus far, the effect of noise on speech communication has been specified in terms of relative intelligibility, or in terms of the necessary distance between speaker and listener for reliable face-to-face communication. For both types of measure the repeatability of the data has been found to be relatively high. Another type of measure is that in which the subject rates the degree of interference directly. Direct ratings may be used in situations when a rapid assessment is required, or when speech intelligibility is so high (i.e., approaching 100%) that intelligibility tests would yield little additional information. Unfortunately, ratings obtained by different subjects tend to differ substantially. Figure 2, for example, shows average ratings of noisiness

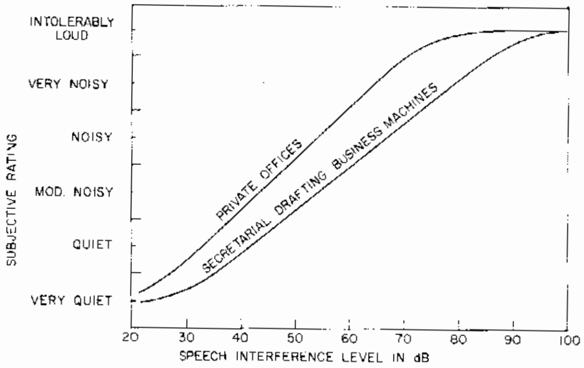

Figure 2. Subjective ratings of noises in offices. The curves summarize in graphical form the results of 100 questionnaires issued during a survey of noise in office spaces (after Beranek and Newman, 1950; see also Rosenblith et al. 1953).

provided by office workers. A seven category scale ranging from "very quiet" to "intolerably loud" was used. The data were obtained by Beranek and Newman (1950) in a survey of noise conditons in three large organizations: a metal producing company, a radio equipment factory, and an educational institution. Although ratings of noisiness were found to increase with physical measurements of the SIL, the ratings of noisiness for private offices and conference rooms are greater than those for stenographic and drafting offices. In a similar vein, Webster has reported ratings of noisiness by ships' personnel that are substantially lower than those of office workers. It would thus appear that ratings of noisiness are very much dependent on who is doing the rating.

Although ratings of noisiness differ substantially among subjects, the ratings are not unrelated to the physical properties of the noise. What is needed is a method of representing the physical parameters of the sound that are relevant to perceived noisiness (or whatever subjective quality is being considered) and which describes how these factors contribute to the subjective impression of noisiness for each subject. The underlying assumption here is that there is a common set of attributes that contribute to noisiness, but that the relative importance of each attribute is different for each subject. As a simple illustration, high-frequency spectral components in noise may be more disturbing to some people than to others. A multidimensional representation is, of course, not a new concept. However, recent developments in multidimensional scaling (Tucker, 1960; Slater, 1960; Shepard, 1962; Coombs, 1965) and the increasing availability of high-speed digital computers provide the necessary analytic and computational tools to make such an approach eminently attractive.

To summarize briefly:

1. The AI and SIL are approximate procedures which provide good predictions of speech interference for a broad, but nevertheless restricted, set of noise conditions.
2. Not knowing all the possible forms that community noise may take, I have instead summarized the basic assumptions underlying the AI procedure and thereby indicated the types of interference for which the AI (and similarly SIL) may not be a valid predictor of speech interference.
3. A characteristic of many types of community noise is that the speech and noise sources are spatially apart. As a rule, spatial separation between the speech and noise sources leads to a reduction in speech interference. Methods of predicting this reduction in interference need to be developed.
4. In summarizing data on speech interference from noise, it is common practice to use averages taken over subjects. Differences between subjects, however, can be substantial and are an important consideration that should not be overlooked in setting criteria of acceptability.
5. A fundamental assumption underlying current methods of predicting speech interference from a single index is that the relevant factors operate in roughly the same way for all subjects. Whereas adequate predictions

may be obtained under certain conditions, the approach is not generally applicable. In particular, the assessment of subjective qualities for which substantial individual differences exist requires a more sophisticated approach. Recent developments in multidimensional scaling may solve this problem.

References

BERANEK, L. L., Design of speech communication systems. *Proc. IRE,* **35**, 880-890 (1947).

BERANEK, L. L., *Acoustics.* New York: McGraw-Hill, 424 (1954).

BERANEK, L. L., and NEWMAN, R. B., Rating of noises in rooms. Presented at a meeting of the Acoustical Society of America, Penns. St. Coll., June (1950).

CARHART, R., Monaural and binaural discrimination against competing sentences. *Int. Aud.,* **4**, 5-10 (1965).

COOMBS, C. H., *A Theory of Data.* Wiley: New York (1965).

FRENCH, N. R., and STEINBERG, J. C., Factors governing the intelligibility of speech sounds. *J. acoust. Soc. Amer.,* **19**, 90-119 (1947).

KOCK, W. E., Binaural localization and masking. *J. acoust. Soc. Amer.,* **22**, 801-804 (1950).

KRUSKAL, J. B., Multidimensional scaling by optimizing goodness of fit to a nonmetric hypothesis. *Psychometrika,* **29**, 1-28 (1964).

KRYTER, K. D., Methods for the calculation and use of the articulation index. *J. acoust. Soc. Amer.,* **34**, 1689-1697 (1962a).

KRYTER, K. D., Validation of the articulation index. *J. acoust. Soc. Amer.,* **34**, 1698-1702 (1962b).

LEVITT, H., and RABINER, L. R., Predicting binaural gain in intelligibility and release from masking for speech. *J. acoust. Soc. Amer.,* **42**, 820-829 (1967).

LICKLIDER, J. C. R., Three auditory theories. In Kock, S. (Ed.), *Psychology: A Study of a Science,* Vol. 1, McGraw Hill: New York (1959).

ROSENBLITH, W. A., STEVENS, K. N., and the staff of BOLT, BERANEK and NEWMAN, Noise and man. *Handbook of Acoustic Noise Control,* Vol. **2**, WADC Tech. Rep. 52-204 (1953).

SHEPARD, R. N., The analysis of proximities: Multidimensional scaling with an unknown distance function. *Psychometrika,* **27**, 125-140, 219-246 (1962).

SLATER, P., The analysis of personal preferences. *Brit. J. Statist. Psychol.,* **13**, 119-135 (1960).

TREISMAN, A. M., The effect of irrelevant material on the efficiency of selective listening. *Amer. J. Psychol.,* **77**, 533-546 (1964).

TUCKER, L. R., Intra-individual and inter-individual multidimensionality. In Gulliksen, H., and Messick, S. (Eds.), *Psychological Scaling.* Wiley: New York (1960).

Community Noise Surveys

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Community noise surveys are concerned with noise levels which are well below those generally considered as incipiently damaging to hearing for long exposure (i.e., well below the tentative ISO rating $N=85$). The following are principal reasons for making community noise surveys:

1. To establish which sources at which times and at what levels are responsible for complaints in various types of neighborhoods.
2. To establish statistically ambient noise climates normally associated with and accepted in industrial; commercial; urban residential; suburban residential; rural communities; and with communities near airports, heliports, transportation centers, etc.
3. To provide practical bases for the establishment of workable zoning regulations and ordinances or laws for the control of potentially noisy activities or operations in or adjacent to various types of neighborhoods, taking into account the character of the community.
4. To provide logical bases for the siting and acoustical design of new structures and operations being introduced into an established community. Such structures often include new electrical substations, sewage and water pumping stations, apartment houses, drive-in restaurants, concert halls, etc.
5. To anticipate the possibility of community complaints as a result of possible changes in operations in an existing accepted facility. Such changes might include daytime operations of an industrial plant being extended into night-time operations, the lengthening of an airport runway, the widening of a main traffic artery to handle more and heavier truck traffic, etc.

The Development of Community Noise Surveys

Serious efforts at community noise surveys were apparently instigated in 1924, when E. E. Free of New York City's *Forum* magazine made audiometer surveys of the city's noise on the streets, extending these to skyscraper offices in 1928 (Free, 1924 and 1928).

Because of insistent complaints about noise, the New York City Health Department established in 1929 a Noise Abatement Commission to make the first community noise survey in depth. It used a newly developed frequency-weighted "acoustimeter" which seems closely related to the A-weighting network of the future generations of sound-level meters now so extensively used, not only in community noise surveys but also in establishing noise limits for noise performance standards set by ordinance or state law and in establishing noise-induced deafness risk criteria. The scope of the commission's work was clearly indicated by its membership, which consisted of representatives from medicine, neurology, otology, law, acoustics, engineering, construction, and the automotive industries. Its final report (Noise Abatement Commission, 1930) is a classic whose noise measurement philosophy is still followed even in the most recent of community noise surveys (Mochizuki and Imaizumi, 1967), although with more sophisticated equipment.

A brief review of the pioneering 1929-30 survey of New York City noise and an outline of the next 25 years of outdoor noise surveys is given by H. C. Hardy (1955). The Greater Chicago Noise Reduction Council, in conjunction with other bodies, sponsored a comprehensive survey of city noise beginning in 1947 and lasting more than two years (Bonvallet, 1950). Traffic, and industrial and residential area noises were studied, including summer and winter, day and night conditons. Apparently for the first time, an attempt was made at some octave-band sound-pressure level measurements in a community noise survey.

City newspapers have been, and continue to be, effective agents in community noise surveys. On the basis of a questionnaire in metropolitan newspapers published by the Noise Abatement Commission in New York's 1929-30 survey, it was revealed that traffic was responsible for 36% of the complaints, public transportation for 16%, radios (homes, streets, stores) for 12%, collections and deliveries 9%, whistles and bells 8%, construction 7.5%, vocal 7%, and miscellaneous 4.5%.

It is interesting to note that about 25 years later (1956) a newspaper poll of the worst noises in New York City placed the noise of refuse collectors and refuse cans at the head of the list, followed in order of decreasing objectionableness by horn blowing, truck and bus acceleration noise, blaring of radio and TV sets, aircraft noise, unmuffled exhaust, street repairs, sound trucks, construction riveting, and doormen's whistles.

A noise survey by the New York Journal American in 1959 is compared with a corresponding noise survey previously made in 1952 (Anonymous, 1959). At corresponding places and corresponding times of day the 1959 sound levels were measured: they were 5 to 11 dB lower in 1959 than in 1952; a sign that some progress had been made in controlling noise in New York City, notwithstanding published statements in the press that for the past 30 years the noise level has gone up one decibel per year. This is, indeed, a most flagrant exaggeration. Table 1 compares the sound levels for various locations in New York City in 1952 and in 1959.

In Germany, the first noise map of Charlottenburg was made in 1938. For Duesseldorf, the acoustics laboratory of the medical academy has charted since 1951 a noise map of the entire area from the standpoint of social hygiene, considering man and his housing and traffic requirements (Meister, 1957). A

TABLE 1. Measured levels as reported in surveys.

Location	Sound Level (dB) 1952	Sound Level (dB) 1959
Times Square	81	76
Union Square	72	64
7th Ave. at 38th St.	80	74
City Hall	70	64
Park Ave. at 49th St.	77	69

recently completed noise map of Dortmund shows the noise levels of important streets and industrial zones. Measurements were made at 1449 points and contours of equal loudness level were marked out in different colors (Anonymous, 1967).

In London, the Building Research Station, the London County Council, and the Central Office of Information conducted a noise survey over 36 square miles of Central London, making noise measurements at 540 equally spaced points, 1500 ft apart, and obtaining the reactions of residents to the noise in a social survey. Compared with the early surveys, in which noise levels were simply read individually from a sound-level meter, the noise levels at each point were automatically sampled by means of tape recordings, once an hour around the clock without an attendant. Playback of the tape was made later through an A-weighting network to give dB(A) levels (Building Research Board, 1963).

The most important conclusion reached from this survey was that 84% of the points showed that noise from road traffic predominated. Industrial noise was predominant at 7% of the locations and building operations at 4%. H. J. Purkis (1964), based on the London survey, deals with aspects and facts about urban noise and considers ways in which urban areas could be planned if traffic noise is considered in determining the amenities of a particular area.

Tolerated dB(A) Levels

By Swiss standards, Table 2 gives the tolerated outdoor noise levels in dB(A) for night and day conditions (Furrer, 1964). Allowable steady noise levels for night and day are given under Basic Noise Level. Frequent peaks may be allowed to go to the levels shown in the next two columns. Infrequent peaks are allowed at rare intervals to reach the still higher levels shown in the last two columns for night and day conditions.

The British Wilson Report (Committee on the Problem of Noise, 1963) recommends that dB(A) levels outside the window of an occupied room nearest a temporary construction site should not exceed the values in Table 3. For dB(A) levels inside dwellings, the Wilson Report recommends that noise levels should not exceed for more than 10% of the time the levels in Table 4.

TABLE 2. Tolerated noise levels in dB(A).

	Basic Noise Level		Frequent Peaks		Infrequent Peaks	
Zone	Night	Day	Night	Day	Night	Day
Hospital	35	45	45	50	55	55
Quiet Residential	45	55	55	65	65	70
Mixed	45	60	55	70	65	75
Commercial	50	60	60	70	65	75
Industrial	55	65	60	75	70	80
Main Road	65	70	70	80	80	90

TABLE 3. Tolerated construction levels at nearest window.

Situation	Level
Rural, Suburban, Urban Areas, Away from Main Road Traffic and Industry	70 dB(A)
Urban Areas, Near Main Roads and Heavy Industrial Areas	75 dB(A)

TABLE 4. Recommended indoor levels.

	Level	
Situation	Day	Night
Country Areas	40 dB(A)	30 dB(A)
Suburban Areas, Away from Main Traffic Routes	45 dB(A)	35 dB(A)
Busy Urban Areas	50 dB(A)	35 dB(A)

Tokyo Community Noise Surveys

As an example of one of the more recent community noise surveys, the Tokyo city surveys are discussed below (Mochizuki and Imaizumi, 1967). These were conducted during December 1965 and January 1966. The city is zoned for residential, commercial, limited (i.e., light) industrial and industrial (heavy) uses. In each zone, plus a suburban zone, 17 typical areas of about 25 acres each were selected and noises measured in dB(A) at 20 points in each area. Readings were taken 50 times at intervals of five seconds to obtain an average and a range. To obtain a temporal distribution of city noise, sound levels at one point in each zone were measured once an hour over a period of 24 hours. A traffic count was also made and the correlation between traffic density and noise displayed. At four points in each zone, sound levels were measured in four time intervals during the day (early morning, forenoon, afternoon, and night).

Figure 1 shows the location of measuring points in a suburban area. The heavy points on the dB(A) charts show the average dB(A) levels at the correspondingly numbered points on the street diagram. The thin vertical lines through these points indicate the range of dB(A) values over a 24-hr

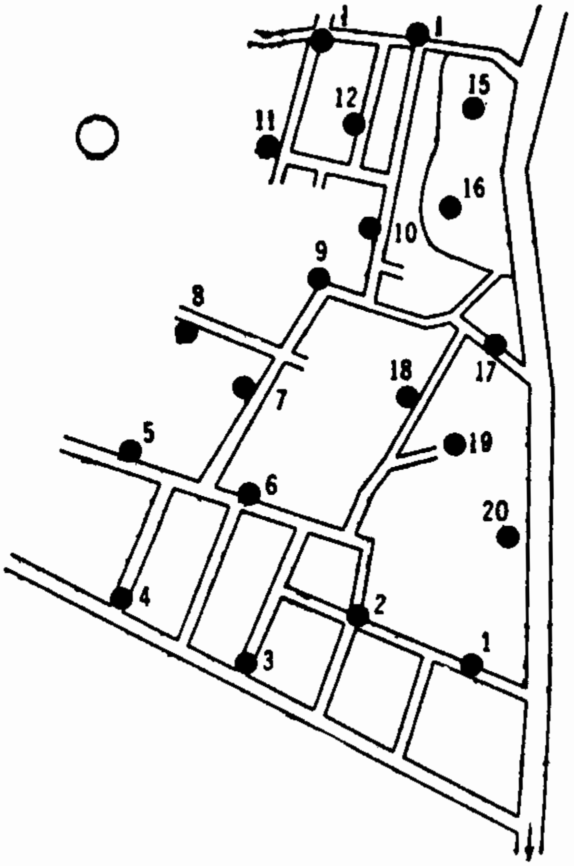
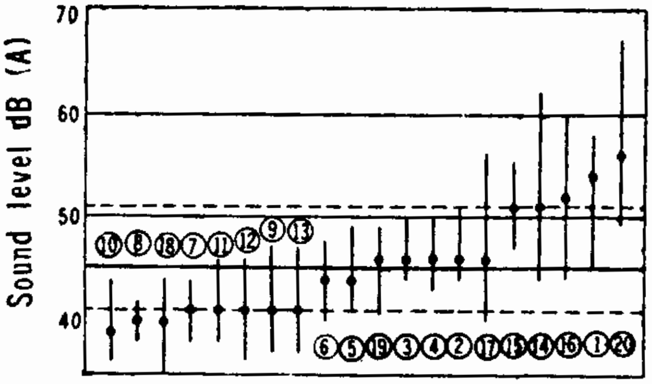


FIGURE 1. Chofushi, an example of a suburban area.



period. Figure 2 shows the corresponding data in a commercial district along a tramway.

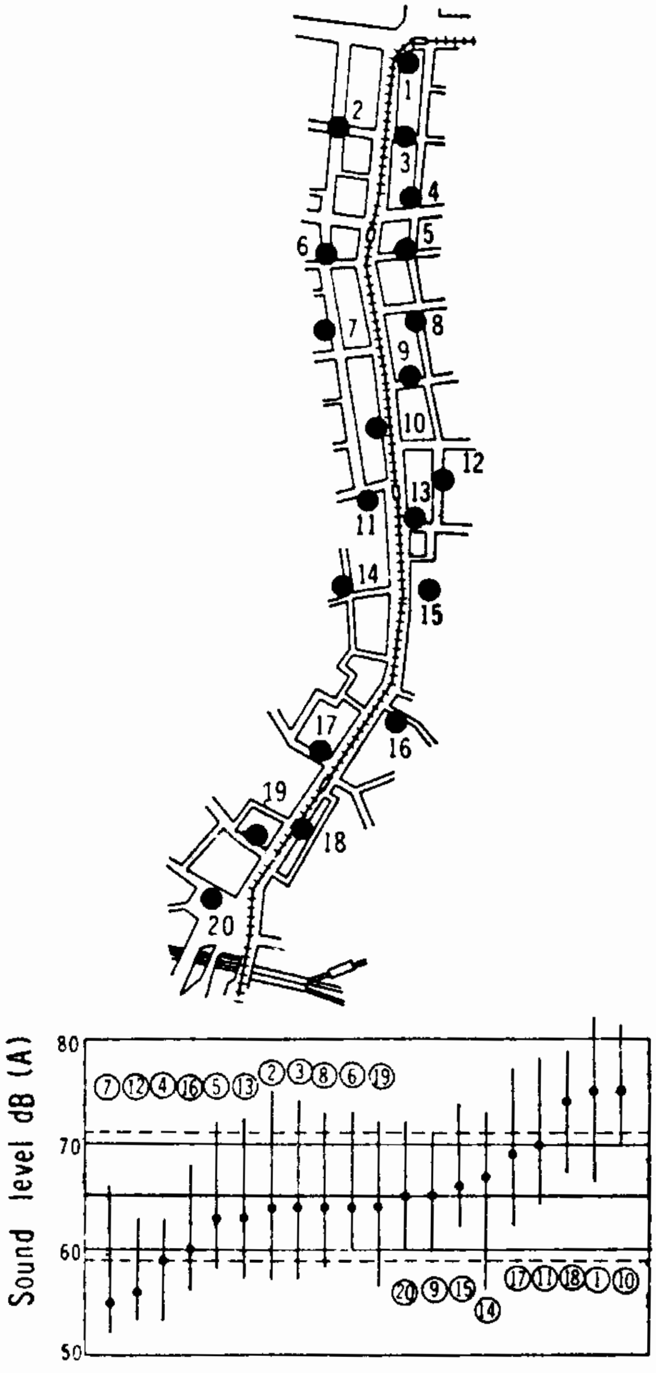


FIGURE 2. Kojimachi, Chiyodaku, an example of a commercial street (along tramway).

Figure 3 shows the distributions over a 24-hr period of dB(A) levels in residential and commercial zones in Tokyo.

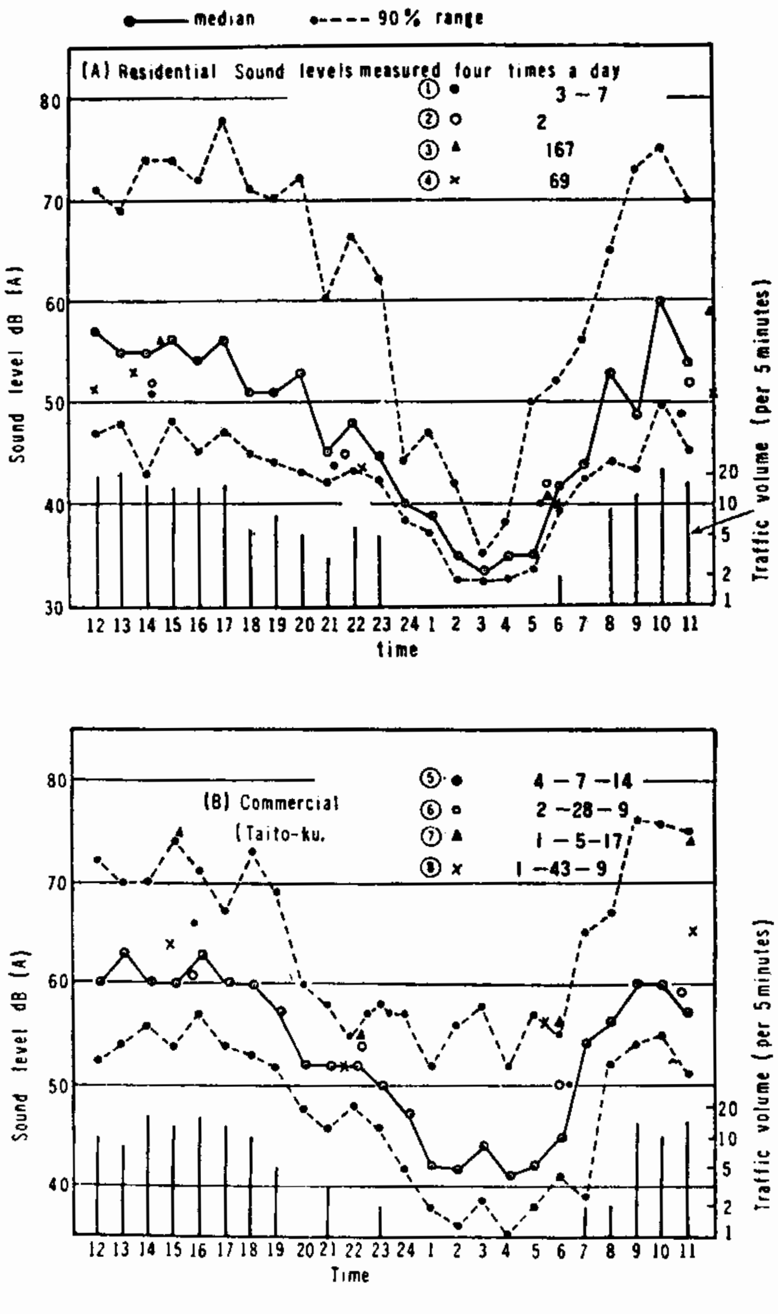


Figure 3. Variation of sound levels measured 24 times a day in every zone.

Figure 4 shows the corresponding distributions in light and heavy industrial zones.

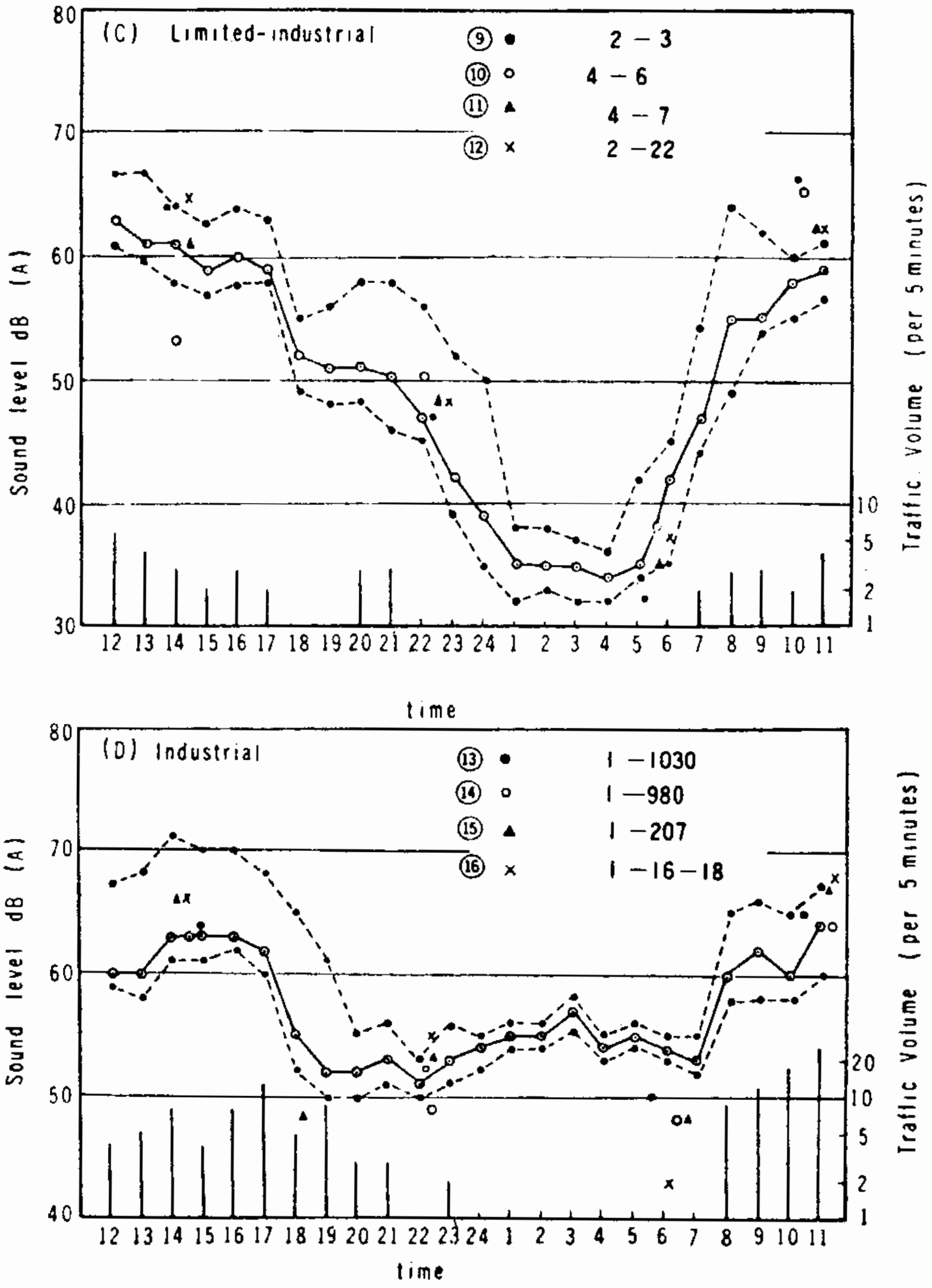


FIGURE 4. Variation of sound levels measured 24 times a day in every zone.

Figure 5 compares dB(A) levels in four places in the four zones in the early morning hours (5 A.M.-6 A.M.) and the late morning hours (10 A.M.-11 A.M.).

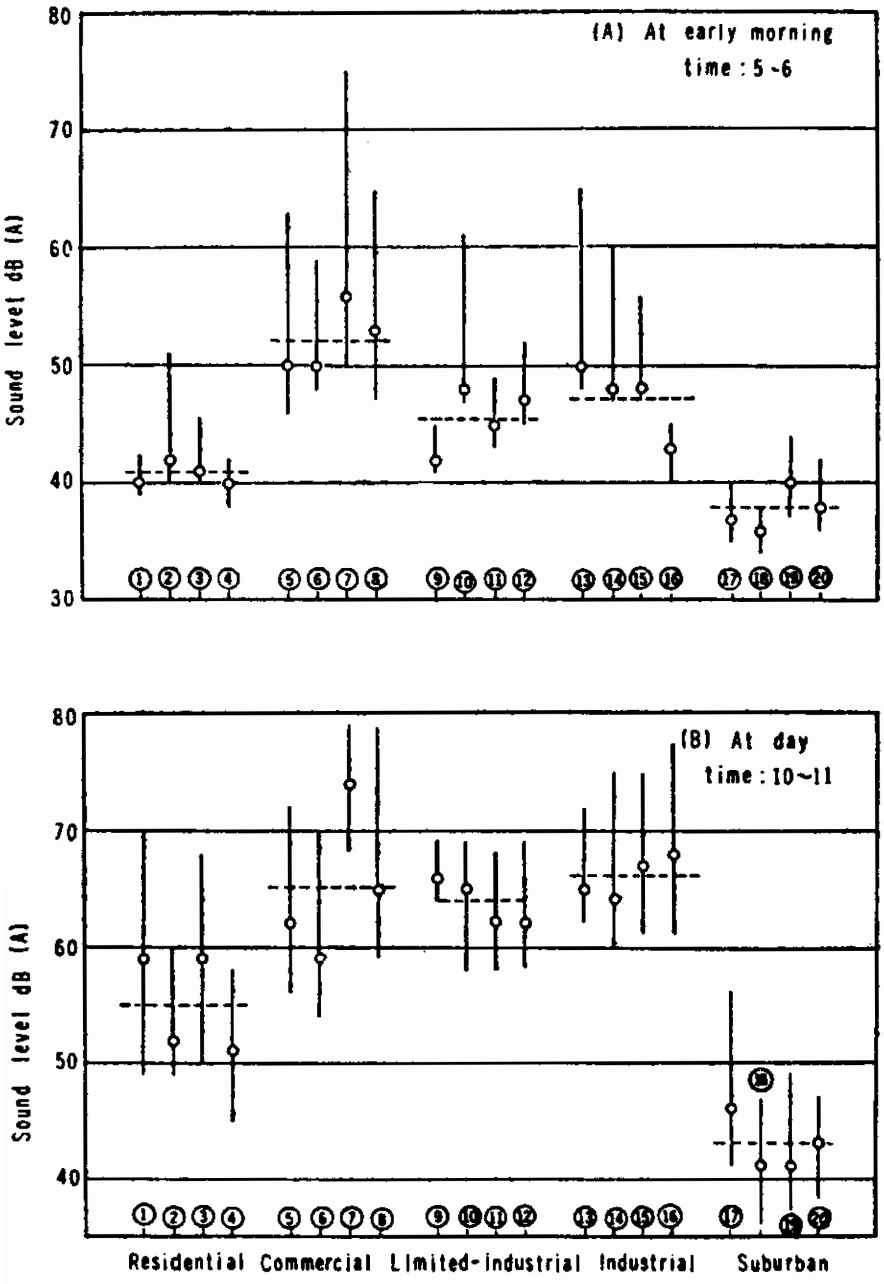


FIGURE 5. Comparison of sound levels by time of day.

Example of Community Noise Survey for Siting Purposes

In order to introduce a large transformer into a residential district, it was essential to acquire a knowledge of the existing minimum ambient levels and make the transformer installation compatible with the existing local acoustical climate. A survey for this purpose was conducted near Manchester, England (Dunsbee and Billingsley, 1967). The survey extended from the city to about 12 miles into the open country. Of the 47 residential areas surveyed, about 50% were suburban, 40% urban, and 10% rural. Measurements in dB(A) were made between midnight and 4 A.M. and only when the weather was fine and calm, in order to obtain ambients at their lowest. Ambient noise was then correlated with traffic density. The authors emphasize three main points learned from this survey: (1) the great predominance of traffic as a source of ambient noise, (2) the difficulty in predicting ambient noise from a description of the locality, and (3) the fact that large, short-term variations of level often occur. The last point in particular makes it difficult to assess the degree of masking which the ambient noise would provide when new noises are introduced into the neighborhood.

Proposed ISO Noise Rating Procedure

Table 5 and Figure 6 show a more detailed and more precise way for rating community reactions to exterior—as well as interior—noises (Kosten and Van Os, 1961). Its adoption by the International Standards Organization (ISO) is recommended. Octave-band community noise levels, either measured or anticipated, are plotted on this chart. The highest penetration into the bands

TABLE 5. Criteria for various circumstances and corrections applicable to dwellings.

Circumstances	*Criterion*	*Corrections for Dwellings*	*Criterion*
Broadcasting studio	15	Pure tone easily perceptible	−5
Concert hall legitimate theatre		Impulsive and/or intermittent	−5
(500 seats)	20	Noise only during working hours	+5
Classroom, music room, TV studio,		Noise during these percentages	
conference room (50 seats)	25	of time	
Sleeping room (see below for		25%	+5
corrections)	25	6%	+10
Conference room (20 seats) or with		1.5%	+15
public address system, cinema,		0.5%	+20
hospital, church, courtroom,		0.1%	+25
library	30	0.02%	+30
Living room (see below for		Economic tie	+5
corrections)	30	Location	
Private office	40	Very quiet suburban	−5
Restaurant	45	Suburban	0
Gymnasium	50	Residential urban	+5
Office (typewriters)	55	Urban near some industry	+10
Workshop	65	Area of heavy industry	+15

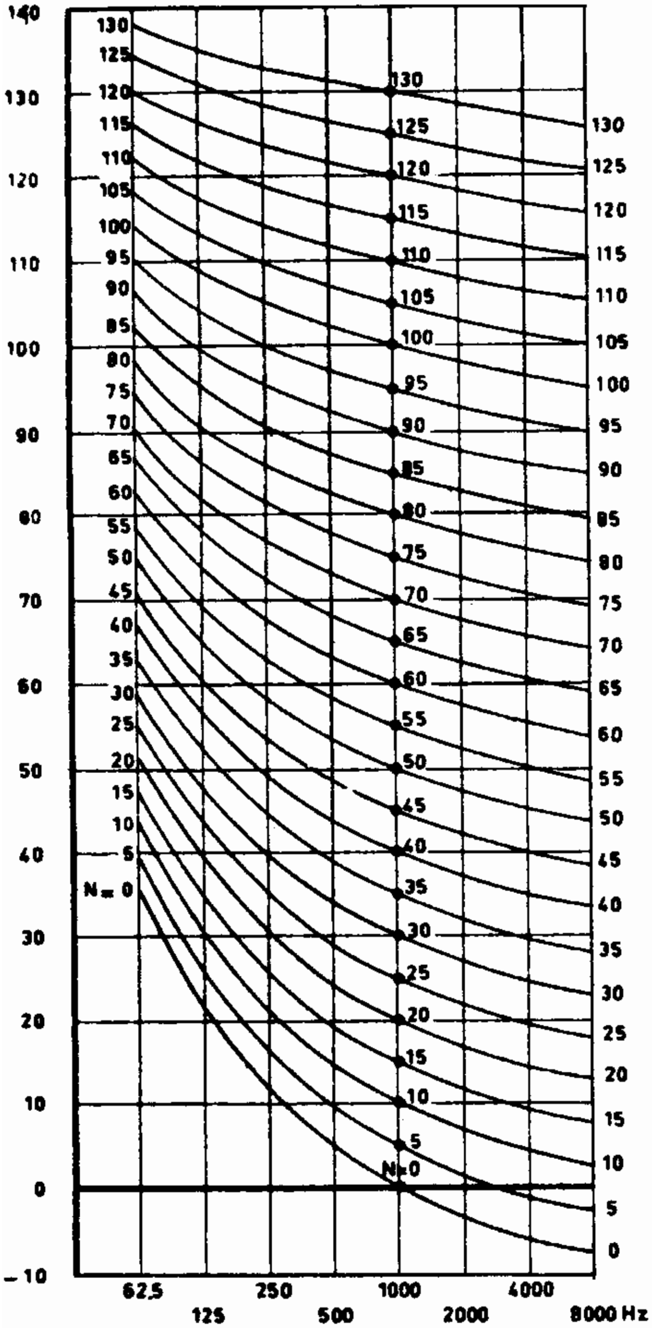


FIGURE 6. Midfrequency of octave band (c/s). Curves for rating noises for acceptability. The ordinate L is octave-band sound-pressure level in dB relative to 2×10^{-4} dyne/cm^2. The parameter is noise rating number N.

between the curves determines the noise rating (N or NR) of steady broadband noise. Thus, if the highest penetration falls between the 55 and 60 contours, the noise rating is N = 60.

For external noise, Table 6 gives the relationship between noise rating and community acceptance on the average.

The "corrected noise rating" is obtained by correcting the actual measured or expected octave-band noise levels for the percentage of time they are on, for the presence of pure tones or impact sounds, etc., as indicated in Figure 6. The corrected noise rating is the significant factor in determining community reaction. The advantage of the octave-band evaluation of community noise, in addition to providing a more accurate evaluation of community response, is in providing knowledge where corrective measures must be taken to bring noise down to a satisfactory level. This is not always possible when a single reading, such as dB(A), is taken as a measure of community noise. The disadvantage of the octave-band evaluation is, of course, the large number of readings or calculations that must be made to cover all the prescribed octave bands.

TABLE 6. Community reaction to noise.

Estimated Community Reaction	*Corrected Noise Rating*
No Observed Reaction	Less than 40
Sporadic Complaints	40–50
Widespread Complaints	45–55
Threats of Community Action	50–60
Vigorous Community Action	Above 65

References

ANONYMOUS, Noise measurements in Dortmund. *Engineer,* **223**, 694 (1967).

ANONYMOUS, How quiet is New York City? *Noise Control,* **5**(2), 44 (1959).

BONVALLET, G. L., Transactions. *Ill.Acad.Sci.,* **43**, 183-188 (1950).

Building Research Board, *Building Research 1962.* London: H. M. Stat. Off., 58-60 (1963).

DUNSBEE, J., and BILLINGSLEY, F., Ambient Noise Levels in Residential Areas. *IEE Conf. Publ. No. 26.* London: Instit. Elec. Engr., 34-37 (1967).

FREE, E. E., How noisy is New York? *Forum,* **75**, 21-24 (1926).

FREE, E. E., Noise. *Forum,* **79**, 382-389 (1928).

FURRER, W., *Room and Building Acoustics and Noise Abatement.* Washington, D. C.: Butterworths, 44 (1964).

HARDY, H. C., Twenty-five years' research in outdoor noise. *Noise Control,* **1**(1), 20-24 (1955).

KOSTEN, C. W., and VAN OS, G. J., Community Reaction Criteria for External Noises. *Nat. phys. Lab.,* Sympos. No. 12. London: H. M. Stat. Off., 373-387 (1962).

MEISTER, F. J., Measurements of traffic noise in West Germany. *J. acoust. Soc. Amer.* **29**, 81-84 (1957).

MOCHIZUKI, T., and IMAIZUMI, N., City noises in Tokyo. *J. acoust. Soc. Japan,* **23**, 146-167 (1967).

Noise Abatement Commission, New York City Department of Health, *City Noise.* New York: Acad. Press (1930).

PURKIS, H. J., Transport noise and town planning. *J. Sound Vibr.,* **1**. 323-334 (1964).

WILSON, A. H. (Chmn), *Noise.* Final Report of the Committee on the Problem of Noise. London: H. M. Stat. Off. (1963).

Effects of Noise on Community Behavior

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In recent years there has been growing concern that man is so wantonly polluting his environment that there is a real threat to his survival. Legislation is today attempting to control air and water wastes, with government regulations already covering the indiscriminate use of poisonous insecticides that could contaminate our atmosphere and soil. Now the issue is raised whether the uncontrolled propagation of noise also constitutes such a health hazard.

Noise has some valuable positive aspects. It often serves as a useful warning of present or impending danger. The cry of a child or a sudden banging in an engine alerts us to possible trouble. Few people object to these noises. Yet, as urbanization and population density accelerate and the number of automobiles, trucks, air conditioners, lawn mowers, airplanes, and countless other mechanical devices multiply, the cumulative volume of unwanted and often annoying noises creates fears that we are adding an additional hazard to our environment. The question is raised as to whether or not there is an upper limit to the level of noise that man can reasonably be expected to accommodate and still continue his desired mode of living.

Over the years, as trains, automobiles, and trucks were first introduced and then grew in numbers, a selective Darwinian process evolved in which many of those persons who couldn't or wouldn't tolerate the new noises moved away from the sources of annoyance, while those who remained exposed to the noise learned to live with it and even to ignore it. After initial usually futile, efforts to control these noise sources, most persons who still objected to them found it necessary to change themselves by changing their locations. The post World War II population explosion into the suburbs and the proliferation of a natural network of high-speed expressways and highways are rapidly eliminating this historically successful escapist solution. The serious alternative, therefore, is being raised again as to whether or not it is socially necessary to modify these once accepted noise sources and make them compatible with community living.

Aircraft noise as a more recent technological product has generally received more public attention in the last 10-15 years than other noise sources. To some extent the problems of aircraft noise are unique. In many other respects, community reaction to aircraft noise involves the same considerations as reaction to other environmental noises and stresses on residential living. Since most of the recent research on community reactions to noise has focused on aircraft noise, the emphasis of this paper will necessarily also be on aircraft noise. Whenever possible the more general aspects of community reactions will be distinguished from those peculiar to the aircraft noise.

About 15 years ago the aircraft industry was shocked by the dramatic temporary closing of Newark Airport. A number of unrelated air crashes had so frightened and antagonized the adjacent communities that the residents had demanded the cessation of all airport activity. Since then the rapid growth of air transportation and introduction of even larger and more powerful jet aircraft engines have created increasing concern about aircraft noise and other disturbances at many airport areas. Efforts have been made to pass and enforce local regulations on aircraft operations and maximum noise levels. Recently local pressures have resulted in introduction of federal legislation to control aircraft noise at all airports in the United States. On November 15, 1967, Alan S. Boyd, Secretary of the newly established Department of Transportation, enunciated government policy on noise:

> The President directed us to "embark now on a concerted effort to alleviate the problems of aircraft noise. . . . Our effort to find solutions to the problems of noise abatement is part of a total departmental effort to insure that transportation activities do not adversely affect our natural environment. . . . Despite our far longer experience with the problems of truck noise and railroad noise, we have not been able to produce quiet vehicles in those modes of transportation. But I am convinced that we will be able, by technological and regulatory means, to reduce the impact of aircraft noise exposure for the majority of Americans who now are, or will potentially be, subject to excessive aircraft noise exposure. Although we have made improvements in some of these areas and research has been underway for some time, we must push far more vigorously for action programs to provide more positive results . . ."[1]

A further statement by the FAA indicates that

> The goals of the Interagency Aircraft Noise Abatement Program will be realized and *a solution to the noise problem will be attained when a state of relative compatibility exists between the airports and the adjacent communities*. This situation must develop in such a manner that aircraft can operate with relative freedom, efficiency, and economy. Such a solution further implies that land usage in the area of airports will be compatible with airborne transportation and that people either residing or working in the area will be sufficiently *protected from the noise environment so that it will be neither harmful nor annoying*.[2]

Prior to these statements which pledge that government will protect people from "harmful and annoying" aircraft noise and also recognizes other long-

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[1] Speech before the Transportation and Aeronautics Subcommittee of the House Interstate and Foreign Commerce Committee on November 15, 1967.

[2] The Federal Aviation Administration Aircraft Noise Abatement Program, a paper prepared by William G. Sperry, John O. Powers, and Stanley K. Oleson, on March 17, 1968, page 5.

standing unsolved noise problems, most spokesmen for government and industry generally indicated that "time would solve aircraft noise problems" just as they thought it had solved automobile and train noise problems. Now that the government realizes that the solution of noise problems requires its positive intervention, the central issue becomes at what levels should noise be limited or regulated, since people vary greatly in their hearing acuity and noise sensitivity. Any noise reduction and control carry their economic price tag and penalty for the noise source. Community studies show that relatively low noise levels annoy some people. Apparently, the key phrase in Boyd's statement is "to reduce the impact of aircraft noise exposure for the majority of Americans. . . ." Even if he did not literally mean more than half the people, it is obvious that the objective, to protect most people from "harmful or annoying" noise, does not include the minority, whatever its number, who are extrasensitive to noise.

A number of empirical community noise studies have been conducted in this country, Great Britain, the Netherlands, Sweden, West Germany, and other countries in an effort to establish quantitative relationships between levels of different noises and their acceptability to different proportions of exposed persons. While more research is still needed and is in progress to establish definitive standards of noise acceptability, enough has been learned to identify the important variables and to indicate the general levels of response. These community studies involve thousands of personal interviews with people living under various noise exposures. Respondents relate the extent to which different noises are heard, interfere with living activities, are annoying, and result in complaint. This complex process, starting with perception of the noise and sometimes ending in complaint, can best be understood if we separate the process into four basic steps.

The first step is to define and measure the sound stimulus to which different people are exposed. Several international acoustic groups have been studying this problem, and it is generally agreed that a combination of three parameters is needed—a measure of intensity, duration, and frequency of stimuli occurrence. As a general index, Perceived Noise Level (PNdB) modified by frequency of occurrence is generally recommended.

The second step is to establish the extent to which levels and types of noise interfere with different living conditions such as relaxation, rest, and sleep; conversation; listening to radio, TV, and records; reading or concentrating; or entertaining friends or relatives; or to what extent does noise make the house shake and vibrate or make TV pictures flicker.

The third step is to determine the extent to which different people are annoyed and irritated by different types of interferences under varying measures of the noise stimulus. A noise can interrupt or interfere with a desired activity, but the human reactions may be either benign acceptance of the inconvenience or it may be strong annoyance and irritation. In investigating these opposite reactions to common noise exposures, the following factors were found to be most important in enhancing or impeding noise acceptability.

A. Feelings About the Necessity or Preventability of the Noise. This involves consideration of whether or not those responsible for propagating the noise are concerned about the well-being of those affected by the noise and are doing whatever is possible to minimize its disturbing impact. If a person feels that those creating the noise care about his welfare and are doing what they can, he is usually more tolerant of the noise and is willing and able to accommodate higher levels of noise. If he feels, however, that the noise propagators are callously ignoring his needs and concerns, he is more likely to be hostile to the noise and more annoyed with even lower levels of noise. This feeling of alienation, of being ignored and abused, is also the root cause of many other human annoyance reactions. This is one of the major reasons cited for urban riots, discontent by minority groups, and more recently of student revolts. Evidence of its significance in explaining variations in annoyance with noise is found in all known community noise studies.

B. Feelings of the Importance of the Noise Source and the Value of Its Primary Functions. If noise is the inevitable by-product of an otherwise valuable service or product, the person is likely to be more tolerant of the noise itself. For example, if one works in a foundry or stamping mill and recognizes the importance and personal benefits from the operation, he is more likely to accept the resulting noise as inevitable. In contrast, the noise from the screeching tires and loud defective mufflers of "hot rods" are almost uniformly annoying to nearby residents, who generally feel that the type of activity is valueless and the noise avoidable.

C. Types of Living Activities Affected. Interference with sleep, rest, and relaxation have been found qualitatively more important and harder to accommodate than interruption of communication, entertainment, etc.

D. The Extent to Which There Are Other Things Disliked in the Residential Environment. It has been found that the more a person dislikes other things about his community, the more hostile he may be to a noise interference, especially if he feels powerless to change other environmental disturbances and if the noise is a more recent addition to his cumulative dissatisfaction. This factor may be especially important in reactions to aircraft noise, which is often viewed as "the straw that broke the camel's back."

E. Belief in the Effect of Noise on General Health. People who feel that noise harms their general health are usually more hostile to the noise source.

F. General Noise Sensitivity. As expected, those persons who are more sensitive to noise in general are less tolerant of any particular noise such as aircraft noise. This is not to say that most persons annoyed by aircraft noise are hypersensitive cranks, who represent at most 1-2% of the population. It merely recognizes the obvious—that the greater the general noise sensitivity, the greater the likelihood of a specific noise annoyance.

G. The Extent to Which Fear Is Associated with the Noise. This is probably the one most important variable which separates reactions to aircraft noise from other noise reactions. Where there is fear of possible air crashes, there is usually more annoyance and less likelihood that adaptation will occur over time. The noise is considered by the fearful as a warning signal. Each and every aircraft noise must be separately decoded as an indicator of danger or safe passage. Regardless of how many past fly-overs turned out to be safe, this one to the fearful might be unsafe. Therefore, regardless of the number of past exposures, the fearful go through a continuous experience of tensions, involving awareness and perception of the noise, decoding of its meaning, and fear until the plane has passed safely. The cumulative effect of such tensions over time is likely to increase rather than diminish annoyance.

In contrast, when fear is not involved in a noise exposure, the possibility of "getting used to" the noise is greater. Our hypothesis is that "getting used to" involves the relegation of a specific noise signal to the undifferentiated and usually unaware background noises. For example, when a particular noise, such as road traffic, is regular and invariant and its meaning is clear and unchanging, the person has no need to perceive and be consciously aware of each separate noise. In fact, if he feels the noise is inevitable and unavoidable and that the road is important and necessary, he will want to ignore the noise and continue about his business. Such a person will often tell the interviewer that he actually does not usually hear the noise.

H. Other Variables. Time will not permit a complete discussion of all the possible relevant human factors affecting annoyance. Some of the other considerations, however, which can be mentioned, are the extent of positive feelings and advantages of the residential area, the extent of permanent attachment or possible mobility regarding the present area, and past history and adaptation to noise environments. Most personal characteristics, such as age, sex, social class, family composition, length of residence, etc., have been found to have little effect on aircraft noise annoyances.

The fourth step is to determine the extent to which people who are annoyed desire to complain and actually do register complaints about noise. To some administrators the only real concern about community reactions to noise is the level of actual complaints. Such a view has been proven very shortsighted and a poor predictor for long-range planning. The level of complaints on any local problem, at any point in time, is a result of a complex interaction of many factors, which will be described briefly. Unless the administrator is aware of the particular combination of these factors at the time that he is evaluating a given level of complaints, he may be sadly misled as to the significance of the complaint activity. A change in the underlying human factors could produce a sharp rise in the number of complaints without any change in the physical levels of noise.

It should be recognized, that in general, very few people will ever register formal complaint with the authorities about any problem. In the British and American surveys only 20-23% of those who felt they had a serious local problem even felt like calling or writing to an official, and but 6-10% said they actually did so. Only 10% said they felt like setting up a committee and 2-4% actually followed through. This small number of activists is related to about 70% of the population who felt they had serious local problems. Thus, it is clear that the number of actual complaints is but the barely visible tip of a huge iceberg. The recent disturbances at a number of universities and throughout France are dramatic examples of this thesis. In all cases a small incident triggered a much wider involvement which spread like wildfire. The *New York Times* editorial of May 19th summarizes the French situation: "The alacrity with which students and workers all over the country launched sit-in strikes . . testifies to the widespread discontent that lay just beneath the surface calm."

Some of the factors which increase the level of complaints at any given time and place follow.

A. *The Relative Intensity of Annoyance.* The more annoyed are more apt to complain.

B. *Personal Variables that Enhance Articulation.* The more educated, with greater income and social status, who are more involved in community organizations and know community leaders and other influential people, are usually more prone to translate annoyance into complaints.

C. *Belief in Usefulness and Possible Success of Complaints.* Those who feel that complaining offers the possibility of a positive result are more prone to complain. Those who feel it is useless to complain won't bother to do so. In the British and American studies, only 10% of all persons with serious local problems felt it would "do some good" to complain.

D. *Pressure of Other Local Problems.* In assessing any one problem, such as noise, the general context of problems competing for attention must be considered. A serious racial crisis, for example, could temporarily mask an equally serious noise problem.

E. *The Availability of Local Leadership and Organizations.* When local leadership opposes complaints, the level of complaints can rise sharply if underlying annoyance exists.

This brief discussion of the more important complex human factors which determine community reactions to noise still leaves the unanswered question "What is the maximum tolerable level?" With respect to jet aircraft noise, it appears to be somewhere in the vicinity of 95-105 PNdB. Above these noise levels, in both the British and American surveys there was a sharp rise in annoyance and complaint reactions, even among those with favorable dispositions to tolerating the noise. In the British study, only 10% of all residents exposed to less than 85 PNdB were greatly annoyed with the jet noise, while at 100-102 PNdB the greatly annoyed jumped to 51% and at 103 + PNdB to 68%. In a current United States study, preliminary results indicate comparable patterns of response. When the study is completed sometime later this year, it should be possible to establish at what levels most people with the most favorable attitudes toward the noise source say they can accommodate the aircraft noise and what levels are too much for them to tolerate. It will then be in the hands of government to establish standards to protect the public.

Community Noise—The Citizen's View

Theodore R. Kupferman

Congressman, New York's 17th District

With so many experts on the panel, it is difficult for a Congressman to know just where to start. This reminds me of the time that my predecessor in Congress, now the Mayor of New York, John Lindsay, was making a tour of inspection of the Federal prison system for the House Judiciary Committee. When he got to Alcatraz he was asked by the warden to talk to the prisoners. He didn't know quite how to begin, for he couldn't very well say, "My friends," or "My fellow Republicans." He just said, "I'm glad you're all here."

I think that might give you some indication of the way different people react to different situations. And as far as noise is concerned, one man's meat is another man's poison.

There's a story of the country cousin coming down to New York City, and walking along with his city cousin at 42nd Street and Broadway. The country boy said, "Stop a minute; I can hear a bird singing." The city boy said, "Nonsense. A bird couldn't exist here on 42nd Street." They walked along a little further and the city cousin said, "Stop! I thought I heard a quarter drop."

My wife has a similar problem. We live in a crowded section of New York City, and she can't stand the street noises at night when she's trying to sleep, so she turns on the air conditioning. The steady hum of the air conditioner helps her to sleep by drowning out other noises. In fact, this is one accepted way to take care of the problem. I've been reading a publication put out by UNESCO, the *UNESCO Courier,* July 1967, and in it there is an article by a Russian, Constantin Stramentov, "Architects of Silence." He talks about the various ways of using noise to cancel out noise.

Incidentally, he's got a good definition of what the words *quiet, please* mean. This is a Russian's view:

> My work demands great concentration and I must therefore preserve the connective functions of my cerebral cortex. I cannot afford to weaken the inhibitory processes and I have to preserve the working capacity of my nervous system.

There's a recent book called *The Company of Animals* where one finds the following on noise:

> The noise of a metropolis is a murmur beside the din of the jungle. The jungle sings, whistles, rings bells, squeaks, squeals, buzzes, plays scales,

> pipes, hoots, howls, scrapes. One cicada I came to know, gargled so well and so monotonously that one almost pleaded with it to *spit.*

A poem by Stewart L. Udall, Secretary of Interior, was published recently in the *Saturday Review*. I'm only going to read the last stanza. It's an anti-noise ode which goes:

> Must all the soft cords go,
> Torn by a savage celerity,
> To caress us only at dawn and dusk?
> Or must we curse the sonic time,
> and brace our ears against the din?

Actually, if we go back far enough, psychological warfare used noise. In biblical times, Joshua at the Battle of Jericho made good use of noise with a blast from thousands of trumpets. Edgar Allen Poe, in his poems "The Telltale Heart" and "The Bells," also used sound to similar effect.

Here is a little poem that I worked on. I called it "Home on the Wane."

> Oh give me a Home
> Far from an airdrome,
> Many miles from the jet plane's loud shriek;
> Where there's no sonic boom to shake up my room,
> And I sleep more than one night a week.

I guess Eugene McCarthy, the Senator from Minnesota, has made it fashionable for politicans to speak in poetic symbols.

I got into this whole question of noise when I was a member of the New York City Council. A judge called me and said that he couldn't sleep at night because of the high-pitched sounds from a roof air-conditioner, and what could I do about it as his representative in the city legislature? I began to understand then what I later read in various medical journals (the last one by Lee E. Farr in *Journal of the American Medical Association* last year) on how you get to be a hypochondriac. I can just visualize the poor litigants before that judge the next day.

I introduced a bill, which is still pending I think, in the City Council, to do something about that. Then I got complaints, from constituents, about transistor radios being played on public transportation so I introduced a bill to make it illegal to play a transistor radio in a public place unless an earplug was used. Robert Alex Baron, now the Executive Director of Citizens for a Quieter City, in New York City, came to me one day. He lived then at the Avenue of the Americas where they were building the extension of the 6th Avenue subway. We discovered that you could get 100 dB simply by listening to the noise coming out of the generators. We called them the "degenerate noise generators." What happened was that all the air compressors and pneumatic drills were going in one place at one time. (Incidentally, Baron is a perfect example of a citizen who takes action, because he's helped organize this group to do something about noise on a much broader level.)We got in touch with the Transit Authority and asked why this noise was going on. We discovered that they didn't seem to know anything about the fact that there were mufflers and silencers that could do something about the noise. Of course, I could then understand how the Transit Authority in New York City might not know anything about noise: All the members had limousines; they didn't even take the subway which they regulate.

When I got down here to Washington at the beginning of 1966 the first thing that I wanted to do was to introduce a bill on noise. After some study I decided there ought to be an Office of Noise Control in the Office of the Surgeon General, so I introduced a bill with a proposed allocation of three million dollars—a relatively minor amount, the way things are done today. The next day there was an editorial in the *Wall Street Journal* about my bill, saying, "The next noise you will hear will be the patter of feet running to get the jobs in the Office of Noise Control." They really misunderstood the nature of the situation, and I could understand why.

People think noise is a local problem—not a problem for the Congress; they don't think of it as a problem for the Federal government. Aircraft, jet noise, and the sonic boom cover a wide ground area; you do think of them in terms of interstate and foreign commerce. But you don't think about noise being a matter of national concern when a building does not have proper acoustics or an automobile goes by in the street, or a typewriter makes too much noise. I understand that kind of reaction. My idea for the Office of Noise Control was to have a central, comprehensive work and planning place where you could, for example, develop a model building code.

We in New York City are buliding what I call the noise slums of the future. Though the building code has provisions for all kinds of other things, there is no provision to do something about the problem of noise. Now the people who manufacture plaster do ask in an advertisement, "When you talk to the wall should your neighbor listen?" because they're interested in selling more plaster. However, we ought to have something about noise control in a model building code. If, as they are trying to do in New York City, a model code were developed, this would be the sort of thing that the Office of Noise Control could disseminate throughout the United States; and help localities to do something about this problem at a great saving.

The *New York Times* had an article about a new prestressed concrete to be used in new apartment buildings in California, to allow faster building. The walls will only be two inches thick. They'll have the proper amount of tensile strength to do this building, but nobody's thought anything about the noise, at least, I don't think they have. I shall be with Soroka next week at the Institute that Berkeley is having on the problem of noise, and while I'm out there I'm going to check with building groups to see if they're doing anything about noise. A friend of mine who went to see the Leaning Tower of Pisa said it was probably built by a California builder.

New York State in July of 1965, passed a law, one of the first in the country, to require control of truck noise on highways. They provided that 88 dB at a distance of 50 ft was the maximum limit.

I was interested to discover when visiting with Jerry Northern, U.S. Army

Captain at the Forest Glen Audiology Group at Walter Reed, that the Army is giving out a circular they get from their own Surgeon General on the importance of hearing conservation programs in the Army. In this circular they discuss the various things that can be done with respect to the noise that can develop in the use of the equipment in the Army.

I received from the Navy a military standard for airborne and structure-borne noise measurements and acceptance criteria for shipboard equipment. In it the Navy speaks of the need to do something about noise in their facilities.

In the Federal government we are doing something about noise; there's no reason why we can't do more in private industry and on local levels. People have a right to complain that it's not being done.

The Pan American Building in New York is one of the great structures at 42nd Street and Grand Central. Provision was made for a helicopter to land on the top of the building. The noise from the helicopter in this area (probably the highest rent area in the world) is just like it used to be when the old Third Avenue elevated went by. You can understand people accepting noise when it's part of the reason for getting cheaper rent, but not when you're paying for something special. The helicopter noise was more than the people in the area could accept; as a result there was a great deal of agitation. I think this may be another reason why the helicopter was terminated for a while, in addition to insufficient income.

And, of course, you know about the sonic boom and the supersonic transport: The United States is putting a tremendous amount of money into building this giant plane and then at the same time the government is trying to restrict travel abroad. So how will anybody use it?

One of the problems we have in connection with airport noise—and I've been at tests at Kennedy Airport in New York City—is that standards are not meaningful. A little black box tests the plane's noise as it goes through a certain area. What happens is that the pilot, risking his safety, the safety of the plane passengers, and the safety of those living in the area, will reduce the amount of noise by cutting the thrust of the engine; then just as soon as he gets by the test spot, he will give it the gun and create a great deal more noise.

We go along on the synthetic belief that something is actually being done about the problem; we just have to be more realistic. That's why I was very happy to see that, in the House, we did put through—without a dissenting vote—a provision for the Federal Aviation Administration to set standards now on noise. I don't expect that the standards will be anything to brag about, but they will be a beginning, just as the truck-noise provision in the state legislature in New York was a beginning.

Zoning is another tool that legislators can use—look at Dulles Airport (Virginia). But one problem Dulles faces, as well as LaGuardia and Kennedy, is that builders try to get variances on zoning because once you've got an airport people are attracted to the metropolitan area. As the city of Washington expands, as eventually it will expand toward Dulles, the builders will be asking for exceptions. I sometimes feel a lack of sympathy for the people who move into an area once it has an airport. It reminds me of the story of the fellow who was arrested for arson and for being drunk after he was taken out of a burning bed in a burning building. He pleaded guilty to being drunk but he denied the arson; he said the bed was on fire when he laid down in it. If you insist on moving into an area where there are airplanes, naturally you cannot expect much sympathy. But people moved into areas when there were not any jets—just DC-3s; now there are jets, and jets make a lot more noise; so perhaps there is something that can be said for their position.

New York City's task force has done some work on noise; for example, they've arranged to get garbage trucks which will make a lot less racket.

Warren G. Magnuson, the Senator from Washington, has his bill for the electric auto, which, if it ever comes to be, will certainly cut down on noise.

I have a quotation form the 33rd Psalm, verses 2 to 4:

> Praise the Lord with harps; sing unto Him with the psaltery and an instrument of ten strings. Sing unto Him and with a new song. Play skillfully and with a loud noise. For the word of the Lord is right and all His works are done in truth.

So sometimes noise can have a good effect. Elwood Driver, who's in charge of the Bureau of Highway Safety in the Department of Transportation, says that he likes to hear the motor when he's in an airplane; in fact, if he didn't the silence would be deafening.

Bill Moyers, who was the President's Press Secretary a while back, once told me he'd studied to be a minister but had gone into politics instead because that's where the sinners were. For those who write, he's now in publishing; so maybe it applies there too. But we, who represent the public, get our absolution from sin by hearing their confession. Their confession is in the nature of complaints—and we get plenty of them. These complaints will mount as we act. I think that Borsky has expresssed it well. People don't normally get around to complaining when they don't know what to do about something; but as we establish the fact that noise is a problem, and as we begin to do something about it, the complaints will certainly come in more and more.

I am glad that this organization is letting us, in the Congress and in other legislatures throughout the country, know what needs to be done. When you tell us what ought to be done, I, for one, will do what I can to see that it is done.

Summary

Ira J. Hirsh

Central Institute for the Deaf, St. Louis, Missouri

A community is a coming together of men, and any time that you have a group of men living together, it means that individuals must give up certain individual rights for the common weal.

Our emphasis in Panel III has been on the residential community, or town, whereas Panel II discussed a different kind of community—the community where people work. We must recognize that our subject involves certain rather special legal and political relations. In Panel II, Leonard spoke about the special relations between an employee and an employer, and how these relations have been covered by certain kinds of statutes. In residential communities, the relations are not quite so direct. The noise may come from agents outside the community, as in the case of transportation noise, and more particularly, aircraft noise. Noises in the community, however, may also come from other members of the community—their power mowers, automobiles, etc.—and they may also come from one's own household. In Panel V, one legal approach to the community noise problem will be taken by Kaufman, whose emphasis will concern the so-called taking of property—particularly relevant to noise sources that come from outside the community.

The legal tradition for regulating disputes between individual members of a community is not quite so clear.

Our panel, and particularly Soroka, has considered the magnitude of the noise problem in the community. We should now be able to relate some of these community noise problems to the various criteria discussed earlier. We should be aware also that community leaders must be told about these different criteria and the necessity of viewing these criteria all together. Kupferman has told us that in New York State a truck cannot make a noise louder than 88 dB(A) at a distance of 50 feet from the highway. I do not know how close to the highway houses are permitted to be, but let us assume that one could be as close as 100 feet. If I remember correctly, at 100 feet this level might be something like 85 dB(A). Now, to be sure, the Thruway Authority has, by this regulation, protected people who live in those houses 100 feet away from hearing damage. But this does not mean that they can talk to each other in those houses. A different criterion must be invoked to estimate what kinds of annoyance or complaint might be obtained from such a community.

Borsky tells us that individual effects are somewhat different from the effects in a group. I think we can judge, from the numbers Soroka has given us, that, considering ordinary community noises, very few people in residential communities will suffer hearing damage. And so this criterion—at least if we use the American Academy of Ophthalmology and Otolaryngology's criterion for an eight-hour day—will rarely be invoked in the case of community noise.

As we've heard from Levitt, interference with speech is a criterion that is probably subject to much treatment, particularly in communities. Difficulties in face-to-face speech communication and the inability to understand speech from the TV set or radio comprise a great proportion of the complaints listed in the social surveys, as mentioned by Borsky. Both Webster and Levitt have indicated that this system—referred to earlier as the articulation index—and the somewhat briefer speech interference level, as a method for characterizing a noise, allows us to predict rather well the kind of speech interference that will come from a particular noise.

In spite of the limitations emphasized by Levitt in his report, it appears that we will have no problem in predicting the speech interference in a living room of a continuously-operating air-conditioner on speech from a radio. On the other hand, noise bursts, best exemplified by a truck passing by or an aircraft flying over, have not been studied lengthily and their effects cannot be predicted so easily from these schemes.

With a graph such as the one accompanying Webster's report, we should be able to specify tolerable noise levels for almost any type of community speech communication; for distances between talker and listener, characteristic of living rooms, of classrooms, or even of bedrooms. Speech interference level appears to be sufficiently accurate for any of these kinds of predictions.

In short, there is no technical barrier to stating what noises can be allowed, if we assume that people in a residential community ought to be able to talk to each other, without amplification and without the special restrictive languages Pickett has discussed.

It is in the third category, "other effects," that things become complicated. We have already said that hearing damage and speech interference can be predicted reasonably well. But both require further work with respect to duration; and speech interference, at least, requires more knowledge about the meaningfulness of that noise, in addition to its acoustical characteristics. Borksy has now suggested that the remaining "wastebasket" category is the most difficult to predict, and at the same time is the major source of community action. Here individual effects and group effects are most difficult to relate. We note that community noise levels high enough to produce hearing loss are rarely encountered; therefore, such levels will rarely produce the physiological effects that were reviewed by Jansen, roughly for the same range of levels. Remember, however, that Jansen also shows some small vegetative reactions, as he calls them, from 70 dB upward. What we do not know is whether the daily invocation of such low-level physiological responses has long-term effects. If such effects can be demonstrated over a long time, then should we wait for community action before being warned?

I mention this to emphasize a worry I have over one point raised by Borsky. He noted there are many factors other than the acoustical specification of a noise that will determine whether or not there will be community action. The question that persists for me is this: If the noisemaker succeeds in convincing a community that his operation is a good thing, and that the noise is really not as objectionable as people think, is this a proper kind of noise control?

Community action may not be an adequate criterion. Kupferman's remarks take us back to some points and principles enunciated by Stewart and, through Rosenblith, by the late Robert F. Kennedy concerning the quality of life. To some people, the quality of life has been improved if one can go faster from one place to another. But such activity lowers the quality of life for others not going anywhere. What is becoming quite clear is that economic progress, savings in dollars, and even the gross national product, are not completely satisfactory criteria for the quality of life.

Several panelists have asserted that technological information is sufficient for more noise reduction than has been put into practice. A manufacturer of power mowers told me that quiet mowers are possible, but that people wouldn't buy them because of the increased cost. I suppose that my neighbor has a right to buy a power mower to cut his grass. But a question that comes up in this context is: Should he have the right to choose a less costly one if its noise is annoying to me?

Continued exposure to noise levels characteristic of discotheques is harmful; should they then be permitted in our communities? Many of us would not want the government to be so paternalistic as to outlaw discotheques. But perhaps, having examined their noise outputs and the effects of such noises on people, we could at least force the proprietors to put up a sign in the entranceway that reads, "Caution: The noise levels inside may be hazardous to your health."

I would like to add one comment on the new community. Borsky has already reminded us about the flight from the city to the suburbs. This is not really a satisfactory solution to the noise problem, even disregarding the sonic boom. Particularly in suburban developments, all but the most costly houses are more lightly constructed than the high-rise apartment houses from which the suburbanite fled. Also, in the suburban community one's neighbor finds more ways to make noise than he did in the city apartment house. Furthermore, if the apartment was high enough, the city-dweller was farther from street noise than he is in the suburbs, particularly if the highway commission or the airport planners operate near his community.

I was brought up in a community near Kennedy Airport, on Long Island. My wife was brought up on a dairy farm, quite far from most noise sources except the purring of the milking machine. When I first brought her to meet my family, I told her, upon meeting her in New York City, that we were going "down to the country" to meet my family. She thought that was pretty funny.

But this was what people in New York City thought of as "country." Since then, suburbia has become itself another kind of city.

There is one aspect of life, or the quality of life, that has been particularly emphasized by the much quoted Stuart Udall, and that is the quality called "tranquility." We still seek tranquility, whether we live in cities or suburbs. In its quest, many of us go camping in the wilderness. The State of Missouri has great camping grounds, where my family and I often seek tranquility. The last time we went there we found we couldn't sleep at night, because our tent has a porous wall and we were surrounded by other campers who had brought their transistor radios from the city. A couple of campers had trailers in which they had television sets.

Perhaps I can help to sum up our discussion by recalling several of the topics discussed. First, there is more technological know-how on noise reduction than has been put into current practice. It has been suggested that such technological developments should be implemented even before economic demands require them. Furthermore, it has been suggested that we acquire sufficient knowledge to set criteria, to agree on measurement scales, and even to set limits on noise. Of course there will be changes that will come with this new knowledge.

This panel has concerned itself with noise as it exists in communities populated by, as Borsky reminded us, frustrated groups who don't think that they can do anything about noise. I believe that we can help them improve their environments when the kind of information discussed here is made available, particularly to the kinds of community leaders to which both the Congressman and Borsky have alluded.

PANEL IV

Special Problems of Recent Technological Development

Opening Remarks

William J. Galloway, Panel Chairman

Bolt Beranek and Newman Inc., Van Nuys, California

As one can see from the titles of the papers to be presented by this panel, jet aircraft, sub- or supersonic, present a number of new problems to acousticians. Indeed, the rapid evolution of aircraft technology, and the noises thus produced, has greatly increased the sophistication required to measure, analyze, and interpret reactions to this noise.

One way to differentiate these new sounds from those with which we have usually been concerned is on the basis of their physical parameters. Both aircraft noise and sonic booms involve relatively short duration events whose amplitudes vary over a wide dynamic range and whose spectra are likely not only to be of a random nature but, in the case of aircraft noise, often contain a rich mixture of discrete tonal components. The noise of a sonic boom sounds quite different from the noise produced by a jet aircraft approaching an airport. Nevertheless, these two sounds impose measurement and data analysis requirements considerably more complex than those often used for most other noises. Detailed knowledge of the time history and spectral content of these sounds is necessary when one wishes to sort out those attributes of the sound which affect the response of people or structures.

Which parameters and scales concern us? And what do their measurements require in the way of instrumentation? First, let us consider sonic boom. Sonic boom is a pressure wave which suddenly, but in finite time, rises to what is called peak overpressure, then decays to a negative pressure of approximately the same absolute magnitude, then abruptly, but again in finite time, returns to ambient pressure. The whole event takes place during a time interval of from less than 100 to as much as 400 msec, depending upon aircraft type and performance. The change in pressure, however, varies from the background level in a neighborhood to an equivalent of 130 dB SPL or more.

In studying sonic booms it has been found useful not only to look at peak overpressure and duration, but more informatively, to perform analyses of the boom "signature" to determine the frequency distribution of energy density (or more practically, mean square pressure). The peak pressure density of a boom may occur at frequencies of a few Hz, while much information may be contained at frequencies as high as 1000 Hz. Thus the measurement and data analysis systems must allow for a dynamic range of the order of 70 dB in a narrow frequency band, and the ability to perform frequency analysis over three decades, starting as low as 1 Hz, for a signal which lasts less than 1/2 sec. Fortunately, magnetic recording techniques using frequency modulation permit such recordings. Capacitor pressure sensors in frequency-modulated carrier circuits are used as extended range frequency response microphones. Data reduction is performed by the use of narrow band filters, often employing speed scaling of the recording tape playback to simplify the filtering process, or through digital frequency analysis on a computer.

Let us now pass from sonic boom to noise from a subsonic jet aircraft. The noise produced on the ground during a jet aircraft flyover does not impose as severe a low-frequency requirement in measurement and data reduction as a sonic boom, yet it has a number of similarities in complexity. A typical sound pressure time history for jets near airports consists of a signal which emerges from the background noise, rises more or less smoothly to a maximum level—which may be as high as 130 dB—then recedes, again more or less smoothly back to the background noise level. The total event will take place in a time interval from a few seconds to more than one minute, depending upon aircraft heights and engine power setting. Most signals of interest have durations in the range of 5 to 20 sec. The signal, therefore, has a change in sound-pressure level of 50 dB or more in a matter of seconds, while its frequency distribution spans the entire audible spectrum.

In the early days of jet noise, the spectrum was a relatively smooth random function having a slightly higher amplitude at the middle frequencies, while dropping somewhat at the low and high frequencies. Such a sound was often described adequately in terms of its maximum amplitude in each octave frequency band, obtained from analysis of a tape recording of the noise, or even as a single sound level meter measurement employing a freqency weighting on the sound level meter such as the "A" scale or the newly proposed "N" scales.

The aircraft engine designs of today and the near future have greatly more complex sound spectra than did the earlier jets. The introduction of sound suppression in engine installation and the development of the turbofan engine have produced not only changes in the shape of the random noise spectra, but, in addition, generation of discrete tonal sounds superposed upon the random noise. Simultaneously, psychoacoustics researchers have found that the temporal patterns of sound, as well as the existence and interactions of the tonal components, are significant elements affecting the way people react to aircraft noise. At present, noise certification procedures are being written to require frequency analysis, in no wider than one-third octave bands, at each half-sec interval of an aircraft noise signal measured during flyover. This implies about several hundred data points to describe the noise from one single flyover at one microphone position! Obviously, the original data must be recorded on magnetic tape for later analysis.

Clearly, with the mass of data necessary for certification purposes, the analysis would be overwhelming if performed with conventional one-third octave band filters. The use of a digital computer seems appropriate. The advent of the "fast" Fourier transform has made noise analyses practical on modern digital computers, and will meet the need of the aircraft noise worker in the future. Indeed, all engine and airframe manufacturers have or are moving towards such digital techniques for noise analyses.

In summary, the new sounds of aircraft require instrumentation capable of faithfully recording short duration noise signals, with dynamic ranges on the order of 50 to 70 dB, and extending in frequency from a few Hz to more than 10,000 Hz. In addition, we find that digital analysis techniques become almost a necessity for the acoustician. The workers in this field require measuring systems which are an order of magnitude more sophisticated, and proportionately more costly than those required for most other noise signals.

Sonic Boom—Results of Laboratory and Field Studies

Karl D. Kryter

Stanford Research Institute, Menlo Park, California

The proposed advent of the Supersonic Transport (SST) for commercial passenger traffic will introduce a new type of noise into man's environment: the sonic boom. The sonic boom problem is interesting from acoustical, psychological, sociological, and political points of view. Because the problem has so many facets we will discuss these in order: (1) the nature of the boom is an auditory stimulus; (2) a field study of the reactions of people to sonic booms and aircraft noise; (3) a review of the laboratory, field, and "real-life" experiments on the effects of sonic booms; and (4) the implications of this research for the operation of the SST over populated areas.

The Sonic Boom

The pressure waveforms and energy spectra of typical sonic booms, called N-waves, are illustrated in Figure 1. The sonic boom can be treated, for practical purposes, as an impulse whose spectrum to a major extent is known from a knowledge of its peak overpressure, rise time, and duration. Methods for converting impulses to spectra of various bandwidths (energy per cycle, per octave, one-third octave, etc.) are available (Sonic Boom Experiments, 1967).

By expressing sonic boom in terms of its energy spectrum we help reveal how it will be perceived by the auditory system in dimensions that are common to all sounds, be they impulsive or steady-state. It is of interest to note, as shown by Zepler and Hare (1965) and Shepard and Sutherland (1968), that the relative perceived loudness or noisiness of one sonic boom versus another boom would be predictable to some extent from loudness or perceived noisiness levels calculated from one-third, or the octave band spectra, of the booms. Figure 2 illustrates how judged loudness and annoyance (or noisiness) varied with rise time and duration.

Although research on the audibility of sonic booms provides insights into the basis of human reactions to sonic booms, of greater immediate interest is research information dealing with how people will behave when exposed to sonic booms in their homes. Two major studies concerned with that question, among others, were conducted by the U. S. Government: one at Oklahoma City (Borsky, 1965) during a six-month period in 1964, and one at Edwards Air Force Base in California in the early summer and winter of 1966 (Sonic

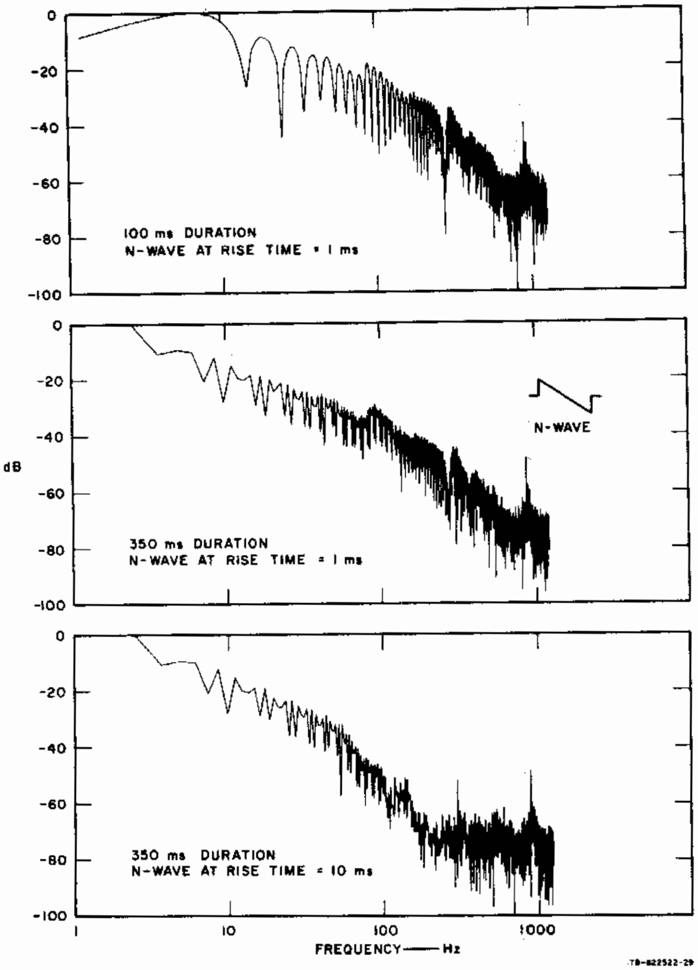

FIGURE 1. Spectral energy characteristics of idealized N-waves. The vertical ordinate has been adjusted to read 0-dB at the frequency of greatest energy (Shepard and Sutherland, 1968).

Boom Experiment, 1967) which we will discuss rather fully below. Other less extensive experiments on the effects of sonic booms on people were conducted in Great Britain and the United States during the period 1962 to 1967. All these studies will be very briefly summarized later in this paper, and Charles Nixon from Wright-Patterson Air Force Base will later discuss in detail the experiments conducted at Oklahoma City.

Sonic Boom Experiments at Edwards AF Base

By means of paired-comparison tests, one should be able to determine the relative effectiveness upon human response of sonic booms that differ with respect to their duration, rise time, or other signature variations. Paired-

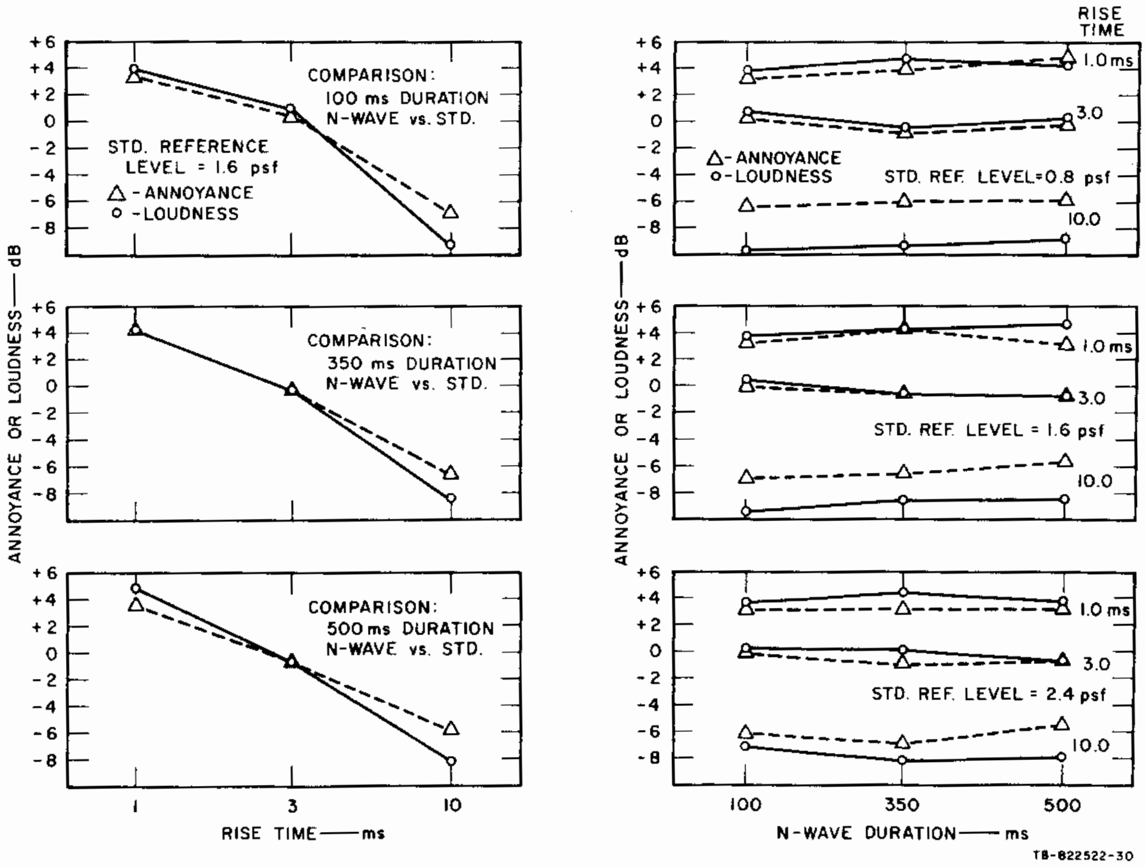

FIGURE 2. Relative loudness or noisiness (annoyance) vs. rise time and vs. duration (Shepard and Sutherland, 1968).

comparison tests also can serve as a means of indirectly determining how people might accept, and what they might do about, sonic booms of various sorts generated by commercial supersonic aircraft and heard in their homes. It is, of course, to be understood that the paired-comparison tests, particularly those involving two sounds differing in spectral and temporal nature, require some validation before they can be accepted with confidence. Fortunately, in the present case, these tests can be validated to some extent for the sonic boom (studies in Oklahoma and in France [Borsky, 1965; de Brisson, 1966], and particularly for commercial aircraft noise near busy metropolitan airports (Borsky, "Community Reactions to Air Force Noise"; Galloway and von Gierke, 1966; Pietrasanta and Stevens, 1958; Stevenson, Rosenblith, and Bolt, 1959). With these thoughts in mind, the following series of experiments using military supersonic and subsonic jet aircraft were conducted at Edwards Air Force Base with subjects placed inside and outside typical residential houses:

1. Paired-comparison tests and absolute ratings of the relative acceptability of sonic booms with the flyover noise from subsonic jet aircraft and the relative acceptability of sonic booms from one type of supersonic aircraft to sonic booms from a second type, and of sonic booms from the same type of aircraft but flown under different operational conditions.
2. An attitude survey of the acceptability of the sonic booms to residents in a military community habitually exposed to sonic booms.

Procedures for Psychological Tests

Over 300 subjects were selected from among residents of the California communities of Edwards Air Force Base, Fontana, and Redlands. They were assigned to various indoor and outdoor test sites at Edwards AFB. The aircraft sounds were presented in pairs with approximately 1 to 2 min between the members of each pair and a minimum of approximately 4 to 5 min between pairs. The subject's task was to indicate on the answer sheet which sound of each pair was the more acceptable if heard in or near their homes and to rate each noise on a 13-point scale from "very acceptable" to "unacceptable."

Results

Boom vs. Subsonic Noise. Figure 3 shows a plot of typical results obtained from the judgment tests. The intensity level at which 50% of the subjects rated one of the sounds in Figure 3 (the noise from the KC-135 subsonic jet aircraft) equal in acceptability to the other sound in Figure 3 (the sonic boom from the B-58 at a nominal peak overpressure of 1.69 psf) was taken as the point at which the sounds are equally acceptable to the subjects. Table 1 gives the intensity in PNdB, required for the noise from the subsonic jet aircraft to be judged equal in acceptability to the sonic booms. The data in Table 1 are taken from graphs similar to Figure 3.

Figure 3 and Table 1 indicate that for indoor listening the noise from a subsonic aircraft (KC-135) at a level of 109 PNdB was about equally preferred

TABLE 1. Results of paired-comparison judgments of relative acceptability of sonic booms vs. subsonic aircraft noise. All overpressure and energy values for the sonic boom and PNdB levels for subsonic aircraft noise are for outdoor measurements. [*Continued next page*]

1	2	3	4		5		6		7	8
Variable	*Subjects From*	*A/C*	*Nominal ΔP*		*Measured ΔP for N Missions—Median of the Medians of 5 Microphones Over N Missions*[4]		*Aircraft Noise when Judged Equal to Boom*		*Number of Subjects*	*N Missions-Number of Pairs of Booms vs. Noises*
							Indoors	*Outdoors*		
Subjects from Different Communities	Edwards AFB	+B-58[1]	1.69 psf*	132.14 dB**	1.94 psf	133.34 dB	109 PNdB	105 PNdB	120	25
	Fontana	B-58[2]	1.69	132.14	1.74	132.39	119	111	98	12
	Redlands	B-58[2]	1.69	132.14	1.73	132.34	118	108	148	12
Different Types of Aircraft	Edwards AFB	+B-58[1]	1.69	132.14	1.94	133.34	109	105	120	25
		−F-104[2]	1.40	130.50	1.40	130.50	107(108)[5]	97(100)[5]	120	13
		XB-70[3]	1.36	130.25	1.35	130.19	107(110)	98(101)	120	4
Booms of Different Intensities from Same Aircraft		F-104[2]	0.75	125.08	0.86	126.27	99(101)	87(89)	120	12
		−F-104[2]	1.40	130.50	1.40	130.50	107(108)	97(100)	120	13
		F-104[2]	2.80	136.52	2.77	136.43	121(120)	117(116)	120	12
		+B-58[1]	1.69	132.14	1.94	133.34	109	105	120	25
		B-58[2]	2.33	134.93	2.56	135.74	114	111	120	20
		B-58	2.65	136.05	2.91	136.86	117	112	120	24

+ The data in these 3 lines are for the same missions.

− The data in these 2 lines are for the same missions.

[1] Aircraft were flown on track 5 miles to one side of test facility.

[2] Aircraft were flown directly over test facility.

[3] Aircraft were flown on track 13 miles to one side of test facility.

[4] The five microphones were arranged at the test facility in a cruciform with a spacing of 100 ft between microphones.

[5] Values reported in a similar table in an Interim Report (July 1967) of the Edwards AFB Study, if different from in the present table, are shown in parentheses. These changes are due to the availability for the present report of physical measurements of some of the aircraft noise not yet analyzed when the Interim Report was prepared.

* pounds per square foot (psf). ** dB $= 10 \log_{10} \frac{p_1^2}{p_0^2}$, and p_0 is 0.0002 μbar (0.0002 dyne × cm²), and p_1 is peak overpressure in bars (or dynes/cm²).

9	10		11		12		13	14
A/C	Difference between Median Measured ΔP and Nominal ΔP (Col. 4 minus Col. 5)		Average Difference between Median of 5 Microphones for a Single Mission and Nominal ΔP*		Average Difference between Median of 5 Microphones for a Single Mission and Median Measured ΔP for N Missions**		Median Measured Duration	Median Measured Rise Time
+B-58[1]	0.25 psf	1.20 dB	0.38 psf	1.75 dB	0.33 psf	0.71 dB	0.171 sec	0.007 sec
B-58[2]	0.05	0.25	0.23	1.17	0.22	1.30	0.183	0.006
B-58[2]	0.04	0.20	0.37	1.60	0.37	1.60	0.197	0.008
+B-58[1]	0.25	1.20	0.38	1.75	0.33	0.71	0.171	0.007
−F-104[2]	0	0	0.22	1.38	0.22	1.38	0.079	0.005
XB-70[3]	0.01	0.06	0.15	0.88	0.15	0.88	0.277	0.006
F-104[2]	0.11	1.19	0.25	2.10	0.21	1.63	0.106	0.006
−F-104[2]	0	0	0.22	1.38	0.22	1.38	0.079	0.005
F-104[2]	0.03	0.09	0.37	1.08	0.27	1.08	0.080	0.005
+B-58[1]	0.25	1.20	0.38	1.75	0.33	0.71	0.171	0.007
B-58[2]	0.23	0.81	0.40	1.28	0.33	1.01	0.160	0.005
B-58[1]	0.26	0.81	0.39	1.17	0.31	1.92	0.148	0.009

+ The data in these 3 lines are for the same mission.

− The data in these 2 lines are for the same mission.

[1] through [5] same as for columns 1–8, previous page.

$*\ \frac{1}{N}\sum_{i=1}^{N}\left|X_i - \text{Nominal } \Delta P\right|$: where X_i is the median of 5 microphone measurement for the i^{th} mission, and N is number of missions.

$**\ \frac{1}{N}\sum_{i=1}^{N}\left|X_i - \text{Median } (X_i)\right|$: where X_i is the median of 5 microphones measurements for the i^{th} mission, and N is number of missions.

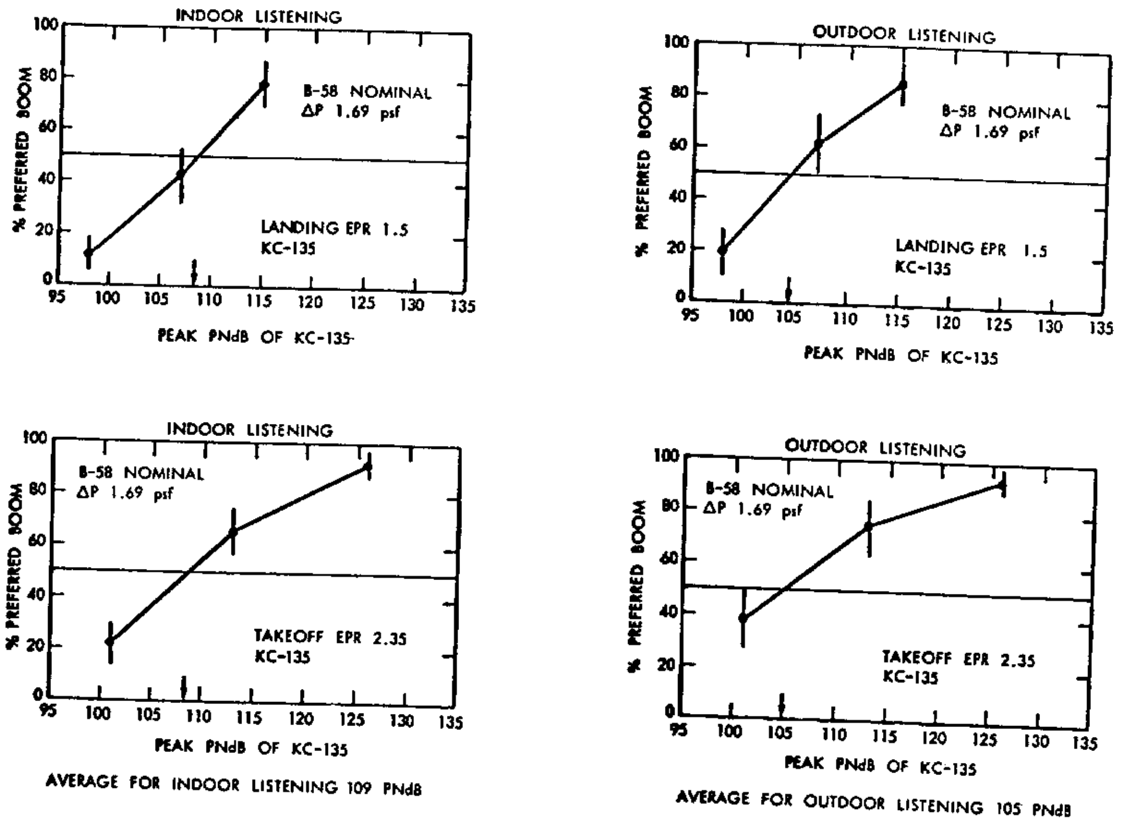

FIGURE 3. Results of paired-comparison judgments of sonic boom vs. subsonic noise (B=58 nominal < P 1.69 psf vs. KC-135). The vertical bars mark the 90% confidence limits of plotted data points. Listeners from Edwards AFB, Phase 1 (Kryter, Johnson, and Young).

to a sonic boom of a nominal[1] 1.69 psf from a B-58. It is interesting to note that for indoor listening when the nominal sonic boom overpressure was increased to 2.65 psf, the PNdB level of the noise from the KC-135 had to be approximately 117 PNdB to be judged as equally acceptable as the boom. This result would perhaps not be expected since increasing the overpressure from 1.69 to 2.65 psf represents only a 4-dB increase in physical intensity, whereas, as judged against the noise from the KC-135, there appeared to be an effective increase in subjective noisiness of about 8 PNdB. Likewise, for indoor listening an overall increase of about 12 dB in the physical intensity of the boom from the F-104 (from 0.75 psf to 2.8 psf) required an increase of 21 PNdB in aircraft noise to maintain equal acceptability of the two sounds.

These results imply that the subjective objectionableness or noisiness of a sonic boom increases at a greater rate than does the noisiness of sound from a subsonic jet aircraft when the intensity of the two sounds is increased by an equal amount. Broadbent and Robinson (1964), by playing back over loudspeakers a magnetic tape recording made inside a structure overflown by a supersonic aircraft, found a somewhat similar but less dramatic difference between the growth (as a function of their intensities) of the unacceptability of sonic booms and aircraft noise.

Indoor vs. Outdoor Listening and Relative Judgments. The data indicate that the boom heard outdoors is more acceptable than the noise of the subsonic jet aircraft (by an amount equivalent to about 5 to 10 PNdB) than when the two sounds are heard indoors. That the results between the relative judgments indoors and outdoors should be even this similar is perhaps fortuitous in that the nature of the two sounds is so different outdoors and because the sounds, due to attenuation by the house and vibrations present indoors, further differ from their outdoor counterparts. Apparently, however, the secondary sounds or "rattles" introduced by the nonlinear response of components of the house to the boom contribute substantially to the subjective unacceptability of the boom heard indoors.

In a previous laboratory test by Pearsons and Kryter (1964) of the relative acceptability of recorded subsonic aircraft noise and a simulated indoor boom, a boom which measured 1.69 psf outdoors, was judged to be equal to the noise of a subsonic jet at 113 PNdB measured outdoors. Broadbent and Robinson (1964), using, as stated, a sonic boom and aircraft noise recorded indoors and played back over loudspeakers to listeners, found a 1.69 psf boom judged as

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[1] The theory used here for the calculation of the nominal peak overpressure takes into account, relative to the generation and propagation of sonic booms, the volume and lift components of the aircraft, temperature pressure, and density changes in the atmosphere which have some influence on boom propagation. The nominal peak overpressures for supersonic aircraft, according to latest theory, agrees within less than 1 dB on the average with actual measured peak overpressures (Col. 10, Table 1). Note also that while the median peak overpressure of five microphones spaced within 100 ft of each other in a cruciform array was, on the average, less than 1 dB from the nominal theoretical value, the variation in peak overpressure among points within that space was, on the average, about 1.5 dB (Col. 11, Table 1). This "fuzziness" in the peak overpressure is found within distances of as close as a few feet and is apparently due to normal, low-altitude atmospheric turbulence.

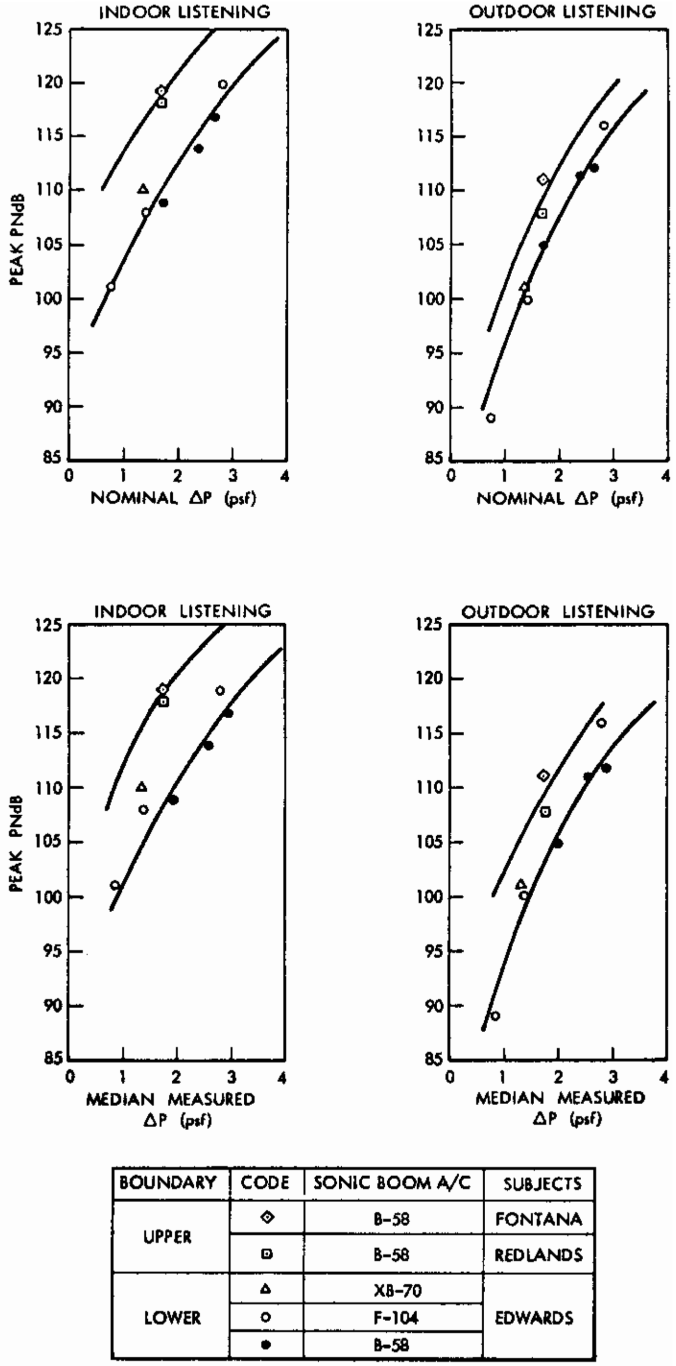
acceptable as an aircraft noise of about 107 to 113 PNdB. These results compare well with 109-112 PNdB noise and nominal 1.69 psf booms found in the present study with actual aircraft to be equal subjectively when heard indoors.

Indoor vs. Outdoor Listening—Rating Scale. The scores on the acceptability rating scales (see Table 2) demonstrate that the booms heard indoors were on the average slightly more acceptable than the same booms as heard by the subjects outdoors—about 34% of the indoor subjects rated the booms as unacceptable when about 47% of the outdoor subjects rated the same booms as unacceptable. The noise of the subsonic jet was also rated more acceptable indoors than it was when heard outdoors, but by a slightly larger degree—41% vs. 23%. Because the house structure should attenuate the aircraft noise by an average of a 30 dB and the sonic boom by 15dB or so (the major energy in the boom is at lower frequencies where the attenuation of the sound by the house is less than it is for the frequency region occupied by the aircraft noise), one might expect the booms and noise to be much more acceptable indoors than outdoors. Apparently, however, people expect and demand a quieter environment indoors than outdoors.

This relatively small improvement in the acceptability of noise, in this case the sonic booms, by virture of the listeners being indoors and therefore somewhat sheltered from the noise, has been found to be true in previous studies of road traffic and aircraft noise (Borsky, 1965; Committee on the Problem of Noise, 1963; Galloway and von Gierke, 1966; Pietrasanta and Stevens, 1958).

Comparisons Among Subjects from Different Communities. Table 1 shows that the subjects from Redlands and Fontana judged the sonic boom from the B-58 compared to the subsonic aircraft noise in much the same way; a noise of 118-19 PNdB was judged equal to the boom at 1.69 psf when heard indoors and to 108-111 PNdB when heard outdoors. Thus, to these subjects the boom was much less acceptable than it was to the subjects from Edwards AF Base (equivalent to a 10 PNdB change in the noise from the subsonic aircraft when heard indoors and about 5 PNdB when heard outdoors). The difference between the judgments of the subjects from Edwards AFB and those from the relatively quiet communities of Fontana and Redlands is illustrated by the extrapolated curves in Figure 4.

An aircraft noise survey showed that the median peak level of aircraft noise in typical residential neighborhoods in Redlands was about 75 PNdB (maximum peak level of about 95 PNdB), and in Fontana about 85 PNdB (maximum peak level of about 100 PNdB); also, these communities were not under or near usual flight tracks for supersonic military aircraft involved in training or test missions. An aircraft noise survey of the residential area of Edwards AFB revealed that subsonic aircraft noise reached occasional peak levels of 110 PNdB; this area, however, was subjected to about 4-8 booms per day for the past three years at a median nominal peak overpressure of 1.2 psf. The subjects had lived on Edwards AFB an average of two years.



BOUNDARY	CODE	SONIC BOOM A/C	SUBJECTS
UPPER	◇	B-58	FONTANA
	⊡	B-58	REDLANDS
LOWER	△	XB-70	EDWARDS
	○	F-104	
	●	B-58	

FIGURE 4. Results of paired-comparison judgments for subjects from different communities. (Data obtained from Table 1.) (Kryter, Johnson, and Young).

TABLE 2. Percentage of persons who rated sonic booms and noises as unacceptable (less than just acceptable). Listeners from Edwards Air Force Base.

SOURCES OF BOOMS AND NOISES						*LOCATIONS OF PERSONS*									
A/C	*Nom. Peak Over-pressure (psf)*	*Alt.*	*EPR*	*PNdB*	*Number of Missions**	*Out-door*	*Block-house***	*El & E2 In-door*	*El-BR*	*El-LR*	*El-FK*	*E2-BR*	*E2-LR*	*E2-DR*	*E2-FK*
B-58	1.69				12	33%	23%	27%	15%	25%	17%	39%	46%	28%	24%
B-58	2.06				4	51	—	37	42	68	20	11	28	73	54
B-58	2.32				11	63	—	28	34	44	6	13	51	38	39
B-58	2.52				2	64	—	49	41	67	32	18	83	92	40
B-58	2.65				8	68	55	62	32	70	52	89	73	56	59
Ave.	2.25					56	—	41	33	55	25	34	56	57	43
F-104	0.70				6	2	—	2	6	0	1	0	0	3	3
F-104	1.36				2	17	—	3	7	0	4	0	0	9	0
F-104	1.40				6	30	—	16	16	12	9	11	9	51	15
F-104	1.50				4	29	—	27	10	29	23	54	43	4	22
F-104	1.69				1	75	—	29	43	38	0	11	22	67	38
F-104	2.00				2	33	—	31	0	7	17	75	57	0	39
F-104	2.80				7	74	—	63	54	50	22	62	89	100	73
F-104	3.30				2	98	—	82	63	75	79	100	79	50	100
Ave.	1.83					45	—	32	25	26	19	39	36	36	36
XB-70	1.38				2	21	—	28	32	15	11	19	39	74	25
XB-70	2.06				4	53	—	25	33	32	9	6	21	68	27
XB-70	2.52				2	65	—	33	55	53	18	10	39	67	28
Ave.	1.98					46	—	29	40	33	13	12	33	70	27
WC-135B		8000	1.76	85	2	1	—	1	0	0	4	0	0	9	0
KC-135		3000	1.5	95	4	2	5	2	0	0	2	3	0	0	3
WC-135B		4000	1.76	95	4	3	—	2	7	0	0	0	0	0	2
WC-135B		2000	1.76	105	9	24	—	11	17	11	5	4	4	17	14
KC-135		1000	1.5	107	4	28	33	22	6	30	21	15	16	11	38
WC-135B		1300	1.76	110	2	41	—	14	0	0	27	5	0	44	15
WC-135B		1000	1.76	113	3	70	—	35	25	50	22	33	15	65	44

WC-135B	800	1.76	115	6	77	—	43	44	56	19	47	24	55	49
KC-135	500	1.5	115	2	80	62	49	19	80	50	80	13	33	59
WC-135B	500	1.76	119	2	92	—	51	38	71	40	53	34	91	52
WC-135B	250	1.76	125	2	94	—	70	53	85	54	78	58	90	81
Ave.			111		47	—	27	19	35	22	29	15	38	32
Number of Persons per Mission					40–48	9–11	51–70	6–8	5–8	8–11	8–10	6–9	5–6	13–18

* The ratings are only for the first aircraft of a pair.

** Used in Phase I only.

It is presumed that the lesser acceptance of sonic booms by the subjects from Fontana and Redlands than by the subjects from Edwards AFB may be due to the adaptation to the sonic booms enjoyed by the Edwards subjects as the result of an average of two years' previous exposure to sonic booms. It was also found, as will be described more fully later, that the residents of Edwards AFB, in reply to an attitude survey, in general believed that their exposure to sonic booms at Edwards made them more tolerant of the boom. Table 3 shows that age and sex were not consistently related to the acceptability rating scores given to sonic booms and the noise from subsonic aircraft.

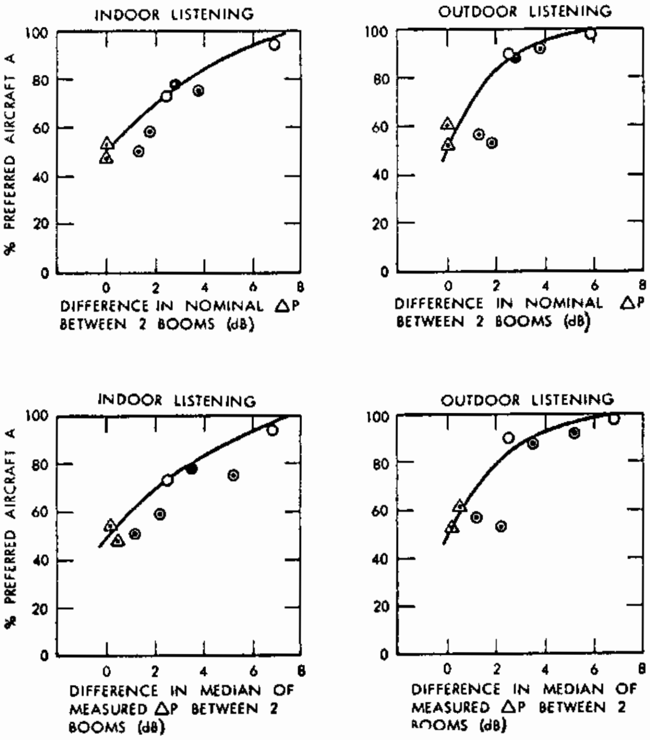
Sonic Booms vs. Sonic Booms. A number of tests were conducted in which the subjects judged the relative acceptability of sonic booms from different supersonic aircraft or from the same type of supersonic aircraft flying in accordance with different or the same operational procedures. Figure 5 gives the results of these tests, which do not show any consistent differences in the aceptability of one type of sonic boom vs. another type of those tested.

Of particular interest is the rate at which the percent preference score changed as a function of a change in peak overpressure. Figure 5 shows that a change of 1.5 dB (about 0.25 psf at a boom intensity of 1.69 psf) for people indoors and 1.0 dB for people outdoors can cause an increase of about 12.5 percentage points in the number of people who judge the more intense boom to be less acceptable. This indicates that the subjective unacceptability of the sonic boom increases at a relatively rapid rate as its intensity level is increased, and at a somewhat more rapid rate for listeners outdoors than for listeners indoors. It was noted before that the rate of growth for unacceptability of the sonic boom appears to be greater than the rate of growth for unacceptability of the noise from subsonic aircraft (a 6-dB increase in the intensity of the sonic boom was found to be equivalent to a 12-PNdB increase in the level of a noise of equal acceptability).

Mail Survey Ratings. Residents of Edwards AFB were asked on July 1, 1966, to rate several noise conditions present in or around their homes on a scale similar to that used by the test subjects: (1) during the month of June when the special sonic boom tests were being conducted; and (2) for the months prior to June. The average daily number of sonic booms at Edwards during the month of June 1966 was about 10 (the residents estimated 6).

Figure 6 depicts the acceptability ratings of environmental noises made by residents of Edwards AFB as a function of their age and years of residence at Edwards. It would appear from this figure that, particularly with respect to sonic booms, the older the person and the longer he or she had lived there, the more acceptable were the noises. Age and years of residence are obviously not independent of each other, and an analysis of the data by years of residence, keeping age constant, showed no consistent influence of age upon the ratings of sonic booms. No significant difference was found between the results of paired-comparison tests for different age groups of subjects.

At the same time it should be noted, as Figure 6 shows, that about 14% of the people who replied to the mail questionnaire rated in retrospect the sonic boom conditions before the month of June as being unacceptable, compared to 26% who rated the booms heard during June as being unacceptable. Part of this difference undoubtedly was due to the difference in boom exposures during these periods. The average nominal peak overpressure of sonic booms during a typical operational month before June 1966 in the residential area of Edwards is about 1.2 psf and the average frequency about four to eight per day. During the month of June, however, about 289 booms were created,



AIRCRAFT A						AIRCRAFT B				
CODE	TYPE A/C	NOMINAL ΔP*	MEDIAN OF MEASURED ΔP*	% PREFERENCE		TYPE A/C	NOMINAL ΔP*	MEDIAN OF MEASURED ΔP*	% PREFERENCE	
				INDOOR	OUTDOOR				INDOOR	OUTDOOR
●	B-58	132.1	133.2	78	88	B-58	134.9	136.7	22	12
○	F-104	131.1	131.2	73	90	F-104	133.6	133.7	27	10
	F-104	131.1	131.8	94	98	F-104	138.0	138.6	6	2
⊙	F-104	133.6	134.0	51	57	B-58	134.9	135.2	49	43
	F-104	130.3	128.7	59	53	B-58	132.1	130.9	41	47
	F-104	131.1	129.2	75	92	B-58	134.9	134.4	25	8
◬	XB-70	133.9	134.4	48	61	B-58	133.9	134.9	52	39
	XB-70	135.6	135.5	54	53	B-58	135.6	135.7	46	47

*IN dB re 0.0002 μbar

FIGURE 5. Results of paired-comparison judgments of sonic booms (of the same type aircraft or two different types of aircraft) at the same and at different nominal peak overpressures in dB. Listeners from Edwards AFB (Kryter, Johnson, and Young).

TABLE 3. Comparison by age and sex of the persons who rated sonic booms and noise as unacceptable (less than just acceptable).

Group	Median Age	A/C	Number of Flights	Indoor Listening				Outdoor Listening				Critical Value at 10% Level of Significance	Decision
				(See notes for explanation of column headings and cell entries)									
				ML vs. MG	FL vs. FG	ML vs. FL	MG vs. FG	ML vs. MG	FL vs. FG	ML vs. FL	MG vs. FG		
Redlands	49	B-58	6	4/10 5/20 0.71	6/17 4/16 0.41	4/10 6/17 0.06	5/20 4/16 0.10	4/15 3/17 0.38*	8/28 3/14 0.25	4/15 8/28 0.02	3/17 3/14 0.07*	2.71	No Significant Difference in the Ratings
		WC-135B	6	2/10 3/20 0.12*	4/17 2/16 0.67*	2/10 4/17 0.05*	3/20 2/16 0.05*	10/15 11/17 0.01	19/28 10/14 0.06	10/15 19/28 0.01	11/17 10/14 0.16	2.71	
Fontana	38	B-58	6	2/5 3/9 0.06*	14/22 11/25 1.81	2/5 14/22 0.94*	3/9 11/25 0.31	1/2 2/6 0.20*	9/14 6/12 0.54	1/2 9/14 0.15*	2/6 6/12 0.45*	2.71	
		WC-135B	6	1/5 0/9 1.94*	4/22 2/25 1.09*	1/5 4/22 0.00*	0/9 2/25 0.77*	1/2 2/6 1.18*	6/14 5/12 0.00	1/2 6/14 0.04*	2/6 5/12 0.12*	2.71	
Edwards AFB	32	B-58	9	2/5 3/7 0.01*	5/23 9/26 0.99	2/5 5/23 0.73*	3/7 9/26 0.16*	1/4 1/3 0.06*	8/19 5/21 1.52	1/4 8/19 0.41*	1/3 5/21 0.13*	2.71	
		KC-135	12	1/6 1/7 0.01*	5/25 4/26 0.19	1/6 5/25 0.03*	1/7 4/26 0.01*	1/4 1/3 0.06*	4/20 5/21 0.09	1/4 4/20 0.05*	1/3 5/21 0.13*	2.71	

* Inadequate sample size

NOTES:

1. The comparisons are based on ratings for the first aircraft of a pair.
2. Symbols for age and sex classification: ML = males whose age is less than the median age; FL = females whose age is less than the median age; MG = males whose age is greater than or equal to the median age; FG = females whose age is greater than or equal to the median age.
3. Differences in the ratings due to age are tested in the columns headed ML vs. MG and FL vs. FG. Differences in the ratings due to sex are tested in the columns headed ML vs. FL and MG vs. FG.
4. Cell entries: Upper left (or upper right) is a/a + b (or c/c + d) where a (or c) is the average number of unacceptable ratings and b (or d) is the average number of acceptable ratings for the designated class. (a + b [or c + d] is the average number of persons in the class.) The lower entry is the value of the test statistic: $\chi^2 = \frac{(ad - bc)^2 (a + b + c + d)}{(a + b)(a + c)(b + d)(c + d)}$. Example: Third row and second column, $a = 14, b = 8, c = 11, d = 14$; $\chi^2 = \frac{(14^2 - 11 \cdot 8)^2 (47)}{(22)(25)(22)(25)} = 1.81$. The adequacy of the sample size depends on the values of a and c in addition to the values of a + b and c + d.
5. Significance test and decision rule: The data are used to determine whether the same percentage of unacceptable ratings occurs for two classes. The hypothesis that the ratings are the same would be rejected if the value of the test statistic equals or exceeds 2.71 at the 10% level of significance (i.e., the probability is 0.10 that the hypothesis is rejected when it is true).
6. Reference 5, Chapter XI, Analysis of Enumeration Data.

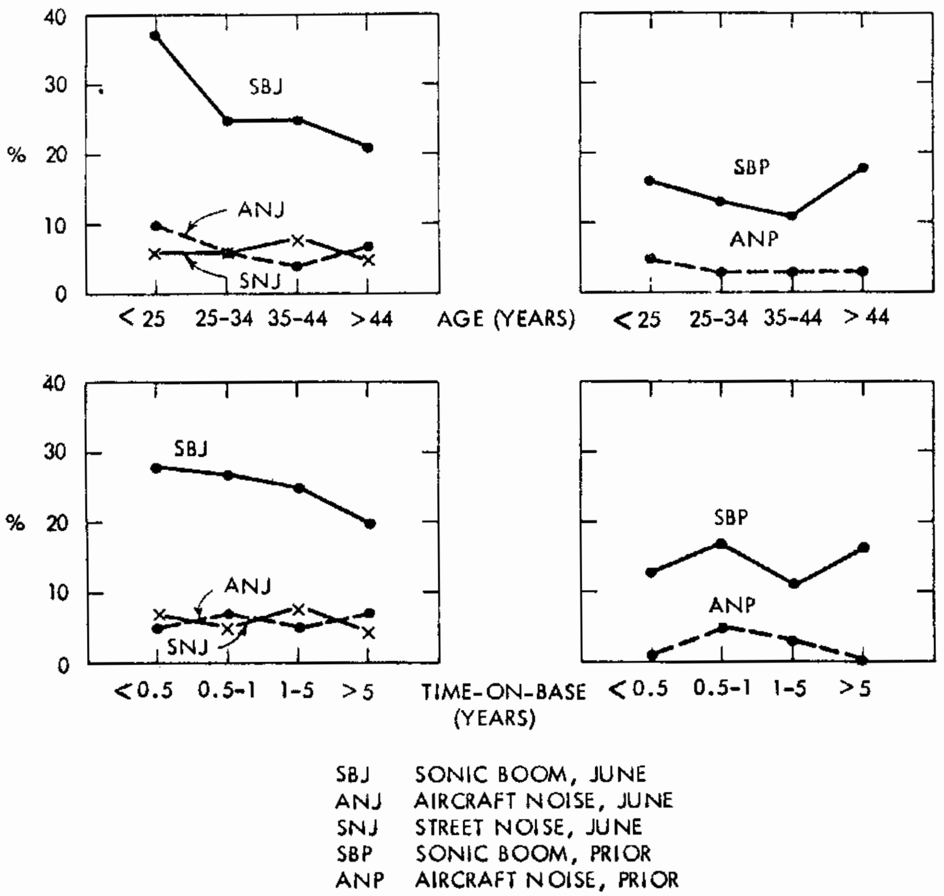


FIGURE 6. Percentage of persons rating sonic booms as unacceptable (less than just acceptable) (Kryter, Johnson, and Young).

giving a daily average of about 10 and a median nominal peak overpressure of about 1.7 psf.

Summary Review of Psychological Research on the Sonic Boom

Essentially two groups of experiments have been conducted that purport to demonstrate what the effects of sonic booms from the SST might be upon people:

1. Attitude surveys and observations of behavior of residents in Oklahoma City, Edwards Air Force Base, and France, when these residents were subjected to sonic booms generated by military aircraft; and
2. Paired-comparison tests conducted in laboratories and under field conditions in Great Britain and the United States in which subjects estimated the relative acceptability, as though heard under real-life conditions, of two

Table 4. Supersonic overflights of civilian communities 1964–1966 U.S. and French Supersonic Military Aircraft. Probable boom—1.2 psf to 1.7 psf in U.S., 1.3 psf in France.

Area of Overflights		*Felt 8–10 Booms per Day Unacceptable due to House Shaking and Startle*	*Paid Claims per Boom per Million People*
Oklahoma City (Legal & Political Reactions)		27% 1.2 psf	0.5
St. Louis 1 Boom, 3 Days Annoying		35% 1.7 psf	5.8
Edwards Residents	14% 1.1 psf	26% 1.7 psf	2.9
French Towns and Country		34% 1.3 psf	–
Pittsburgh		1.7 psf	6.8
Chicago		1.7 psf	6.1
Milwaukee		1.7 psf	5.8

Table 5. Estimated 1975 population under each sonic boom category for great circle routing of medium (1200–1800 miles) and long-range (2000–2400 miles) SST routes in the U.S.A. Because of overlapping boom paths across the country some relatively small regions of the country will receive more booms per 24-hour period than will other regions. It is seen that about half the total numbers of people given in the Table would receive 10 or more booms per day, and the remainder would receive less than 10 booms per day.

Expected Number Booms Per 24-Hr) Period	*Population Within*			
	Boom Path 50 Miles Wide	*(CNR)*	*Boom Path 25 Miles Wide*	*(CNR)*
1–4	52,400,000	92–103	26,200,000	95–103
5–9	25,200,000	98–106	12,600,000	101–106
10–19	19,500,000	101–109	9,750,000	104–109
20–34	29,400,000	104–112	14,700,000	107–112
35–51	2,900,000	107–115	1,450,000	110–115
TOTAL	129,400,000		64,700,000	

Table 6. Estimated median boom intensities of possible overland SST operations of Boeing and Concorde under and to the side of flight path.

	Under Flight Path		*12.5 Mi to Side of Flight Path*	
Median Boom Intensities	*Transsonic*	*Cruise*	*Transsonic*	*Cruise*
Boeing	2.1 psf	1.8 psf	1.6 psf	1.3 psf
Concorde	2.0 psf	1.9 psf	1.5 psf	1.4 psf

sounds presented in rather rapid succession (a boom vs. fly-over noise from a subsonic aircraft, and one boom vs. a different boom).

Table 4 gives the essential findings of attitude surveys conducted in cities exposed to sonic booms from military aircraft.

Implications of the Psychological-Sociological Research for Commercial SST

As stated, research on the effects of sonic booms on people could presumably for extensive, commercial transportation. Table 5 gives the numbers of people on the ground who would be exposed to sonic booms that would create various equivalent Composite Noise Ratings (CNR) from commercial SST carrying but 50% of the anticipated air passengers in the USA on city-pair flights longer than 1200 miles. Table 5 shows that approximately 50 million people would be exposed to 10 to 51 booms per day, or an environment earning from booms alone, a CNR of between 101-115. These CNR values (Bolt Beranek and Newman, 1966; Galloway and von Gierke, 1966) indicate that there would be strong complaint and legal action taken against the sonic boom.

Other factors besides the reaction of people to sonic booms disfavor the full development and use of the SST over populated areas. At the time of this writing no final decision regarding the future use of the SST has been reached. Table 6 gives the estimated median boom intensities of possible overland SST. operations of Boeing and Concorde.

Bibliography

Andrews & Associates, Inc., and Hudgins, Thompson, Ball & Associates, Inc., Structural response to sonic booms. Final Report SST65-1, to Federal Aviation Agency (February 1965).

Bolt Beranek & Newman Inc., Land use planning with respect to aircraft noise. AFM 86-5, TM 5-365, Navdocks P-98 (Joint Manual of the U. S. Departments of the Air Force, Army, Navy. Also issued by Federal Aviation Agency as Tech. Rep. by BBN (October 1966).

Borsky, P. N., Community reactions to sonic booms in the Oklahoma City area (Parts I and II). Wright-Patterson AFB, AMRL-TR-65-37, AD 613 620 (1965).

Borsky, P. N., Community reaction to Air Force noise, Part I: Basic concepts and preliminary methodology; Part II: Data on community studies and their interpretation. NORD, WADC TD 60-689, Wright-Patterson AFB, Ohio.

Broadbent, D. E., and Robinson, D. W., Subjective measurements of the relative annoyance of simulated sonic bangs and aircraft noise. *J. Sound Vibr.*, **1**, **162-174** **(1964)**.

Committee on the Problem of Noise, Final Report, Noise. London: Cmdn. 2056, Her Majesty's Stationery Office (1963).

Cornell Aeroautical Laboratory, Analysis of population size in the sonic effects zone along SST routes. SST Memo No. 507, Contract FA-WA-4297 (October 1964).

deBrisson, L. C., Opinion study on the sonic bang. Centre d'etudes et d'instruction psychologiques de l'armee de l'air, Study No. 22 (1966), Royal Air Est. Lib. Trans. No. 1159 (1966); AD 483 066.

Galloway, W. J., and von Gierke, H. E., Individual and community reaction to aircraft noise; present status and standardization efforts. London Noise Conference (November 1966).

Grubb, C. A., Van Zandt, J. E., and Bockholt, J. L., Report on data retrieval and analysis of USAF sonic boom claims files. Tech. Rep. No. 4, Stanford Research Institute, Contract AF 49(638)-1696, with Nat. Sonic Boom Evaluation Off.

Johnson, D. R., and Robinson, D. W., On the subjective evaluation of sonic bangs. Great Britain: Nat. Physical Lab. Applied Physics Div. Report prepared for Ministry of Aviation, AP 25, GC, 1147/66/1 (November 1966); and *Acustica*, **18**, **241-258** (1967).

Kryter, K. D., Laboratory tests of physiological-psychological reactions to sonic booms. *J. Acoust. Soc. Amer.*, **39**, S65-S72 (1967).

Kryter, K. D., Psychological reactions to aircraft noise. *Science*, **151**, 1346-1355 (1966).

Kryter, K. D., Concepts of perceived noisiness, their implementation and application. *J. Acoust. Soc. Amer.* **40** 344-361 (1968).

Kryter, K. D., Johnson, P. J., and Young, J. R., Psychological experiments at Edwards AF Base. Stanford Research Institute, Interim and Final Report, Contract AF49 (638) 1758, Nat. Sonic Eval. Office.

Lundberg, B., Pros and cons of supersonic aviation in relation to gains or losses in the combined time/comfort consideration. *Royal Aeronaut. Soc. J.* (September 1964).

Lundberg, B., The menace of the sonic boom to society and civil aviation. Stockholm: The Aeronautical Research Institute of Sweden, FAA Memo PE-19.

Mills, C. H. B., and Robinson, D. W., The subjective rating of motor vehicle noise. *Engineer*, **211**, 1070-1074 (1961).

Nixon, C. W., and Hubbard, H. H., Results of the USAF-NASA-FAA flight program to study community responses to sonic booms in the Greater St. Louis Area. Nat. Aeronaut. & Space Admin. Tech. Note No. D2705 Hampton, Va.: Langley Research Center (1965).

Pearsons, K., and Kryter, K. D., Laboratory tests of subjective reactions to sonic booms. Nat. Aeronaut. & Space Admin. Contractor Report No. CR-187 (1964).

Pietrasanta, A. C., and Stevens, K. N., Noise exposure in communities near jet air bases. *Noise Control*, **4**, 29-36 (1958).

Pollard & Associates, Report of survey: Structural damage and repair, residential and commercial buildings. Oklahoma City, 1963-1964. Prepared for FAA under Contract No. FA65AC-1167-1, April 1965.

Sawyers, K. N., Calculated underwater pressure levels from sonic booms. Interim Tech. Rep. No. 8, Stanford Research Institute. Contract AF 49(638)-1696, with National Sonic Boom Evaluation Office.

Shepard, J., and Sutherland, W. W., Relative annoyance and loudness judgments of various simulated sonic boom waveforms. Prepared for NASA, Stanford Research Institute Contract NAS-1-6193, Subcontract Lockheed-California Company, B-87017-US (1968).

Sonic Boom Experiments at Edwards Air Force Base. National Sonic Boom Evaluation Office, 1400 Wilson Blvd., Arlington, Virginia (1967).

Stevens, K. N., Rosenblith, W. A., and Bolt, R. H., A community's reaction to noise: Can it be forecast? *Noise Control*, **1**, 163-171 (1959).

Van Os, G. J., and Van Steenbrugge, B., Recent experiences with noise acceptability criteria for dwellings. Proc. 5th Intl. Cong. Acoustics (September 1965).

Webb, D. R. B., and Warren, C. H. E., An investigation of the effect of bangs on the subjective reaction of a community. Royal Aircraft Est. Tech. Rep. No. 66072 (March 1966).

Webb, D. R. B., and Warren, C. H. E., Physical characteristics of the sonic bangs and other events at Exercise Westminster. Royal Aircraft Est. Tech. Rep. No. 65248 (November 1965).

Wiggins, J. H., Jr., The effects of sonic boom on structural behavior—a supplementary analysis report. Prepared for Federal Aviation Agency by John A. Blume & Associates, SST 65-18 (October 1965).

Zepler, E. E., and Harel, J. R. P., The loudness of sonic booms and other impulsive sounds. *J. Sound Vibr.*, **2**, 249-256 (1965).

Laboratory Studies on the Effects of Duration and Spectral Complexity on Subjective Ratings of Noise

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Perceived noise level (PNL) has been used for several years in rating the noisiness of aircraft flyovers (Kryter, 1960, 1961). This method weights the sound-pressure level in the various frequency bands of noise according to the noisiness of the individual bands and recombines these individual measures to give a single number for the perceived noise level in PNdB (Kryter and Pearsons, 1963, 1964) were conducted by presenting pairs of sounds with method was not intended to apply to sounds with sharp discontinuities in their spectrum, such as those produced by discrete frequency components. In addition, the method was to be used to predict the noisiness or unwantedness of sounds of equal duration. No attempt was made to account for any duration differences of the sounds. Subsequent to the original development of the perceived noise level, effects of duration and tones on judged noisiness were explored in numerous experiments.

Duration has been defined for this purpose as the amount of time the sound is within 10 dB of its maximum level. This definition, although somewhat arbitrary, appears to correlate well with the subjective judgments discussed below.

Tests to investigate the magnitude of the duration effect (Kryter and Pearsons, 1963, 1964) were conducted by presenting pairs of sounds with different duration to groups of subjects, and asking which of the pair was more disturbing. By varying the levels of the sound, the tradeoff between duration and level was determined. The range of durations tested initially was from 1.5 to 12 sec. The time pattern was trapezoidal as shown in Figure 1. The sound stimuli for the test included two broadband spectra, a ⅓-octave band of noise, and a helicopter recording. The results indicated a 4.5-dB-per-doubling tradeoff. That is, for two sounds to be judged equally noisy when one is twice as long as the other, the longer sound must be 4.5 dB less in level.

Since many aircraft flyovers last longer than 12 sec, additional tests have been conducted to extend the range to 64 sec (Pearsons, 1966). These tests utilize the time patterns shown in Figure 2. The triangular time pattern "A" was selected to represent a flyover noise while the square time pattern "B" was selected to represent ground runup noise. Sounds for this test included a 1000

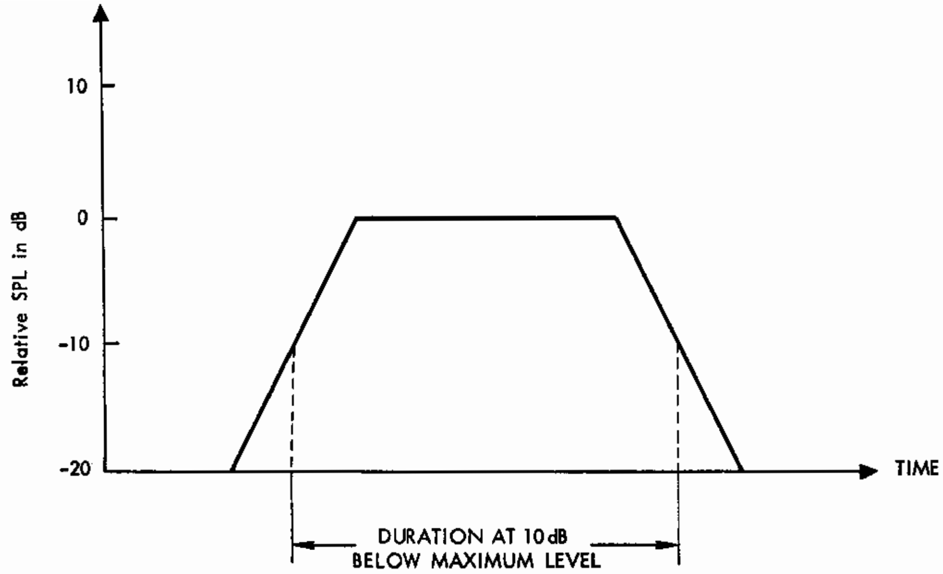

FIGURE 1. Time pattern of signals employed in initial judgment tests on duration.

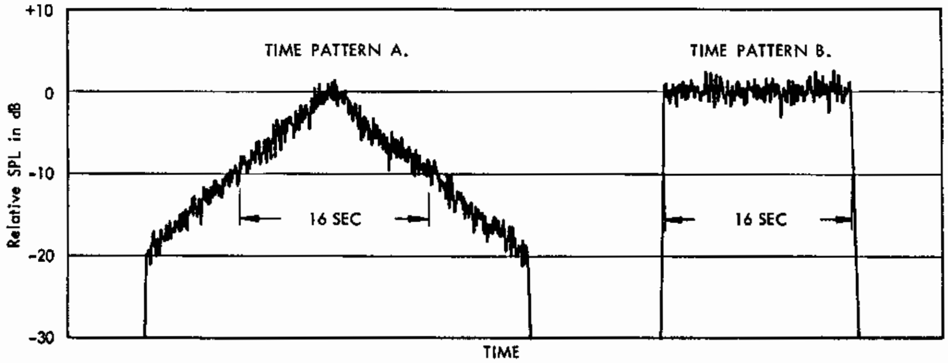

FIGURE 2. Measured time patterns of 1/3-octave-band noise employed in judgment tests on duration.

Hz pure tone, a 1000 Hz ⅓-octave band of noise, and a broadband noise. The combined results of the two tests are shown in Figure 3. Notice that the results do not lie on a single straight line. For the shorter durations from 1.5 to 4 sec, this tradeoff or slope is 6 dB per doubling while for the range from 16 to 64 sec, the slope is 2 dB per doubling. For practical purposes, an average slope of 3 dB per doubling, indicated by the shaded area, over the range from 4 to 64 sec appears to be a reasonable compromise. Thus, for aircraft flyovers, most of which lie in this range, correction of 3 dB per doubling of duration is recommended, which corresponds to additivity on an energy summation basis.

Although most people recognize when a tone exists in a sound sample, it becomes a bit more difficult to describe physically when that tone exists. Figure 4 shows a ⅓-octave band spectrum analysis of a sound with a prominent pure tone at 1000 Hz. The amount the tone exceeds the noise we define as the tone-to-noise (T/N) ratio.

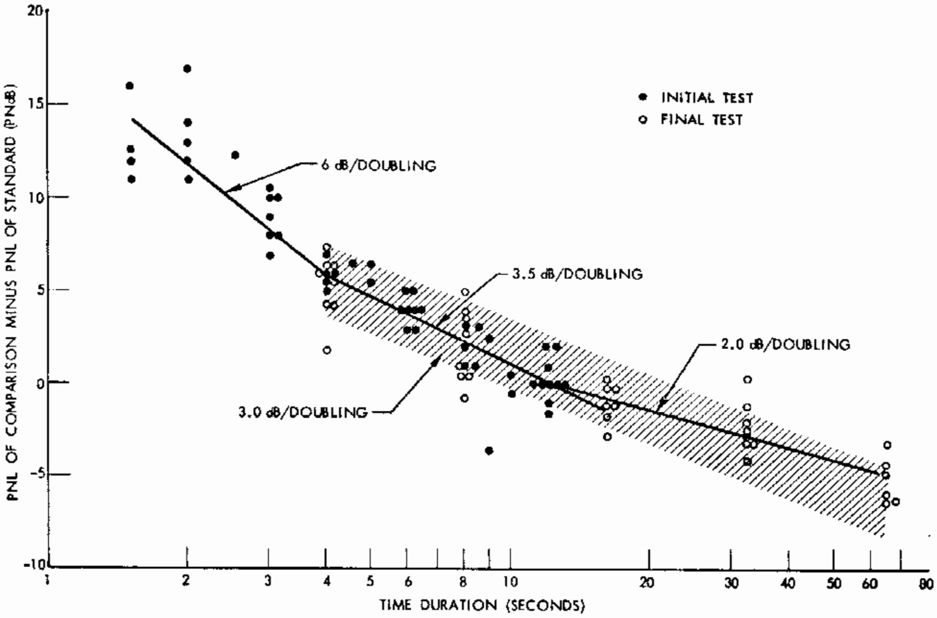

Figure 3. Summary of equally acceptable noises of various durations (combined tests 1.5-64 sec).

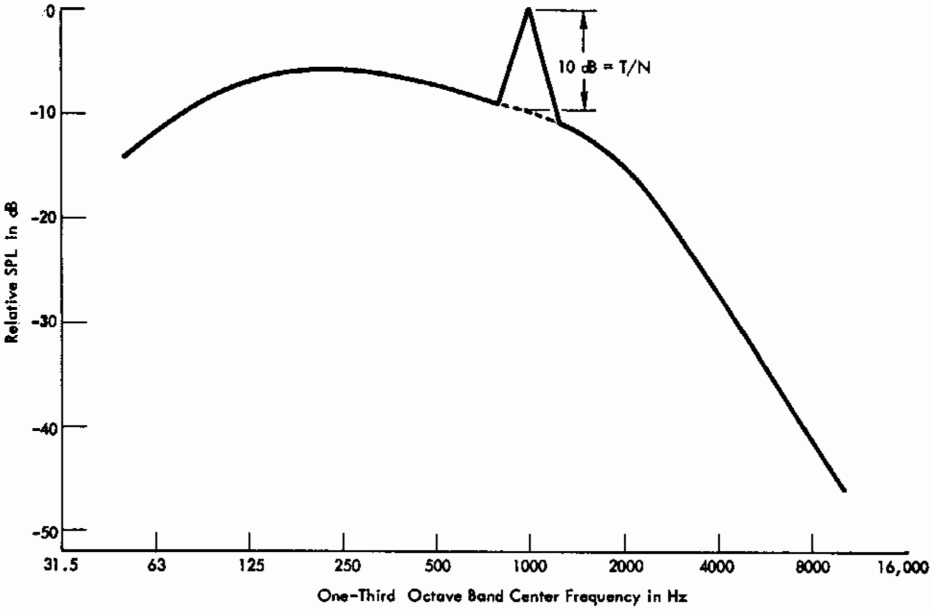

Figure 4. Broadband sound with prominent tone at 1000 Hz.

To determine the magnitude of the effect of pure tone on judged noisiness, judgment tests were conducted using octave bands of noise mixed with pure tones at various tone-to-noise ratios (Kryter and Pearsons, 1965). Figure 5 shows a sample of results for 1000 Hz. Note that as T/N ratio increases, the correction necessary to account for the tone also increases. The correction itself is applied to the ⅓-octave band spectra before calculating perceived noise level. In general, the pure-tone correction increases as a function of frequency and T/N ratio.

Additional tests were conducted to see how well these corrections predict the noiseness of tones in broadband noise (Pearsons, Horonjeff, and Bishop, 1967). Figure 6 shows the ⅓-octave band spectra of the two broadband noises used. The Noy noise spectrum represents an equal noisiness contour while the jet noise spectrum is similar to that of a jet flyover at 2000 ft. For comparison, single tones were added at frequencies ranging from 250 to 4000 Hz. Tone-to-noise ratios for these tests were 25 dB as measured in ⅓-octave bands. Figure 7 shows the results of these tests presented at judged equal noisiness. This and succeeding figures depict the level of the comparison relative to the level of the standard at judged equality of noisiness for a stated calculation procedure. In this type of presentation, if the comparison calculated for the noise spectra at the level of equality is less than the standard it will be plotted as a negative value. If the calculated comparison value for judged equality of noisiness is the same as the standard value, it will be plotted as zero in the graphs. Naturally, the best measure is the one for which the levels of the standard and comparison values are equal (comparison re standard is zero). Notice in the figure that as the frequency increases the need for correction

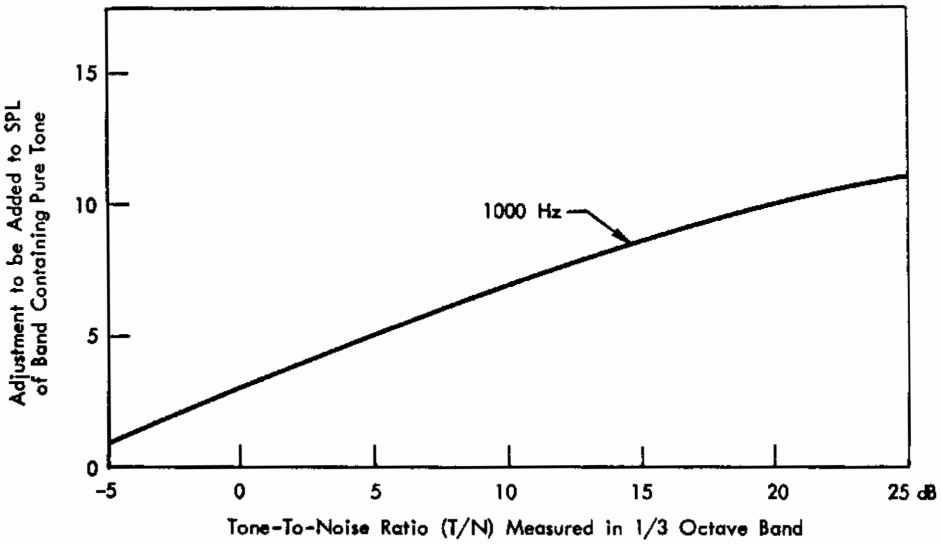

FIGURE 5. Adjustment to be added to SPL of band at 1000 Hz containing pure-tone component prior to calculation of perceived noise level.

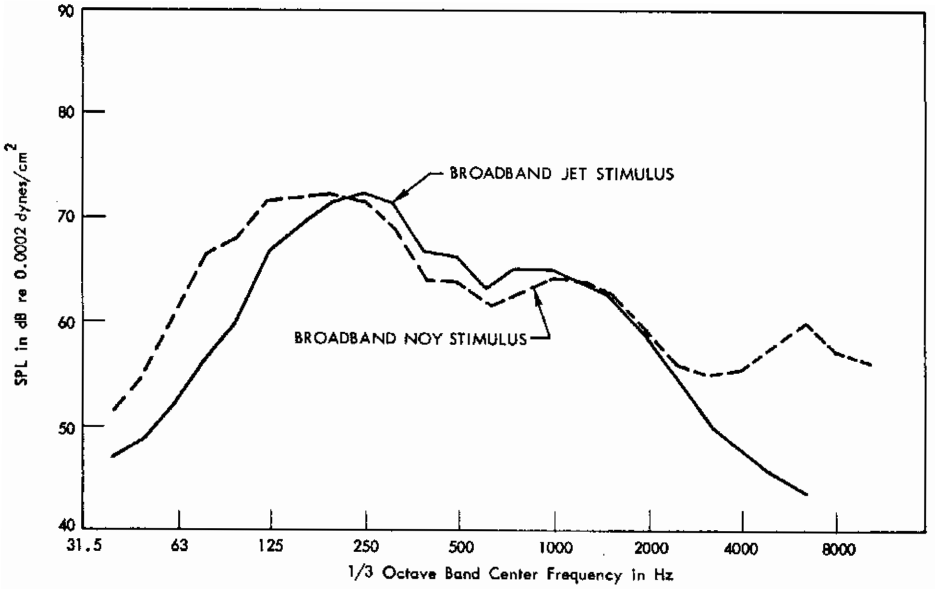

FIGURE 6. Average noise spectrum of broadband "jet" and "noy" stimuli used as comparison standard.

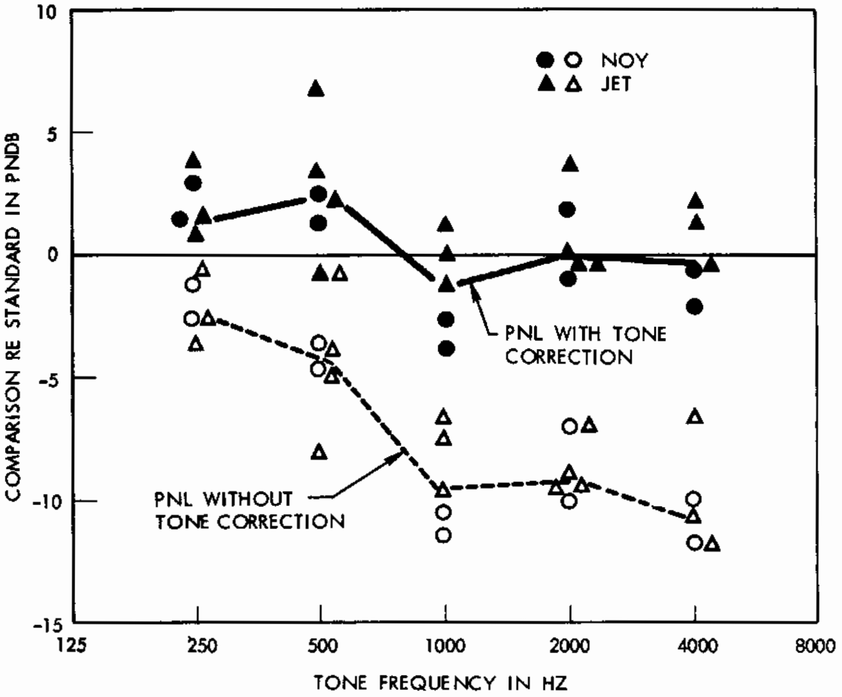

FIGURE 7. Judgments of equal noisiness for single tone and broadband noise (comparison) vs. broadband noise (standard).

increases. Using the correction described previously appears to bring the results into better agreement, although there is some tendency to overcorrect at the lower frequencies.

In actual aircraft flyovers the tones are not as pure and steady as those applied in these tests. Also, more than one discrete frequency component occurs in actual aircraft flyovers. For these reasons additional tests were conducted utilizing multiple and modulated tones and broadband noise as stimuli (Pearsons, Horonjeff, and Bishop, 1967).

The stimuli for the modulated tone tests consisted of a broadband jet noise standard. For the comparison stimulus a 500 or 2000 Hz tone was added to the noise. The tone was modulated either in frequency or in amplitude. Modulation rates for both AM and FM ranged from 5 Hz to 300 Hz. Figure 8 shows the results of this test. Here again we present comparison standard for the results in perceived noise level both with and without tone corrections. Amplitude modulation is shown on the left and frequency modulation on the right with a steady-state tone shown in the center. The figure indicates the rate of modulation increasing in both directions from the steady-state tone shown in the center. In general, the results for the steady-state tone do not differ greatly from the modulated tones. The one exception to this is the amplitude modulated tone at 5 Hz. This may be due to the impression of beats or large

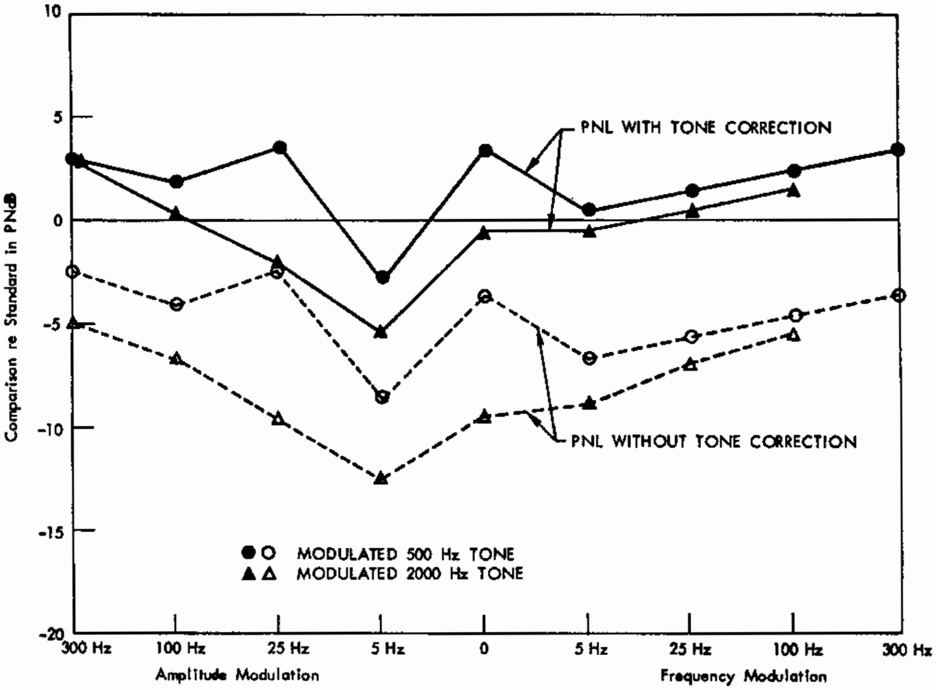

FIGURE 8. Judgments of equal noisiness for modulated tones in broadband noise (comparison) vs. broadband jet noise (standard).

irregularities in the signal quality which is absent from the other modulated tones. In any event, the results using perceived noise level corrected for pure-tone content are in much closer agreement with the judgment data than are the results without the tone correction.

Now let us consider the multiple tone stimuli. The broadband noise stimuli for this test used the same spectra as that in the modulated tone test. The tone stimuli added to the noise consisted of two- and five-tone complexes. Table I shows frequency and range of these stimuli. Tone-to-noise ratio for all these stimuli was again 25 dB as measured in a ⅓-octave band.

Figure 9 presents a summary of the results of the multiple tone tests for judged equal noisiness. Here we show average results using the calculated perceived noise level with and without tone correction. Again it appears that the results with tone correction agree more closely with the judgment data than those without tone correction. However, the method does tend to overcorrect the multiple tone stimuli that have a lower frequency component at 2000 and 4000 Hz.

Although not shown in the figure, the results of the test indicated there was little difference between the judgments of harmonically related tones (those with one and two octave spacings) and nonharmonically related tones (those having spacings of 1/10, 1/3, and 4/3 octaves).

Figure 10 shows the results for a 16-tone complex, for a two-tone and five-tone complex, and for a single tone at 250 Hz. The two- and five-tone complexes had spacings of two octaves as compared to the four-octave spacings for the 16-tone complex. Notice that for the 16-tone complex, the large negative value for the perceived noise level without tone correction is in poor agreement with the judgment results. If we apply the tone correction for the 16-tone complex there is good agreement with judgment results. Figure 10 suggests that, as we increase the number of tones in a complex, the noisiness increases. Part of this may be attributed to the different range of frequencies involved. This increase was not apparent for the two- and five-tone complexes of matching ranges employed in the major portion of the test.

Since the noisiness of aircraft flyovers is influenced both by duration and discrete frequency components, it seems necessary to determine at some point whether the correction procedures developed for tone and for duration effects work in a combination. Some preliminary work along these lines has been

TABLE 1. Frequency and range of 2-tone and 5-tone stimuli.

Frequency of Lowest Tone in Hz	*Range in Octaves*
250	1/10, 1/3, 1, 4/3, 2
500	
1000	
2000	
4000	

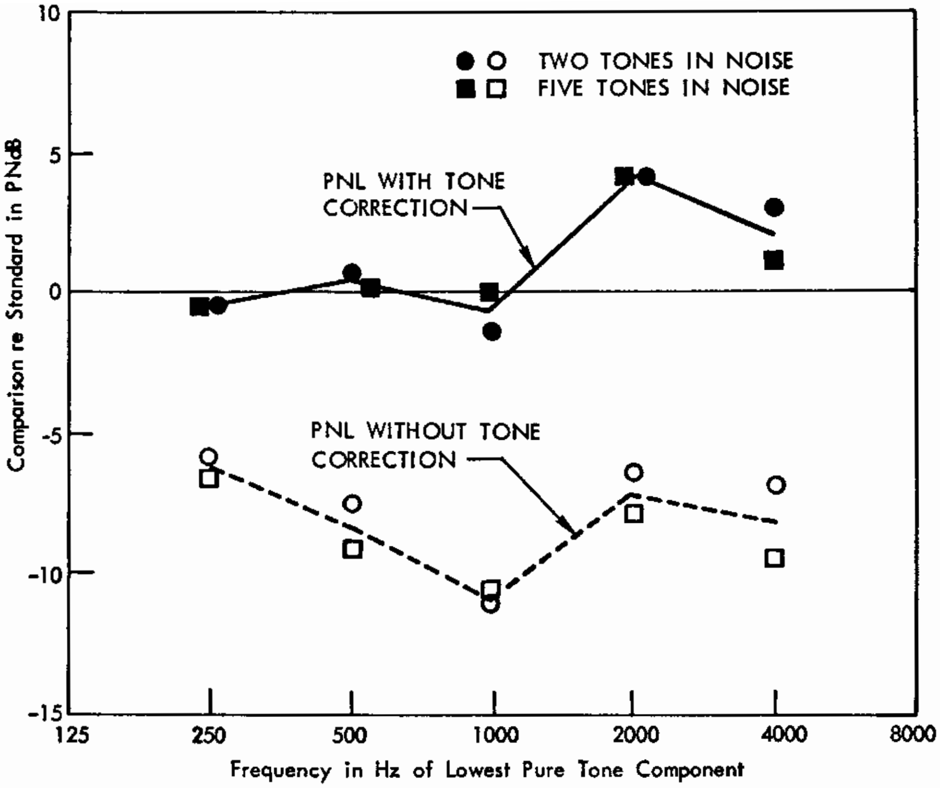

FIGURE 9. Mean values of equal noisiness judgments of two and five tones of varying frequency spacing in broadband noise (comparison) vs. broadband jet noise (standard). Note: The maximum frequency spacing was varied in steps of 1/10, 1/3, 1, 4/3, and 2 octaves.

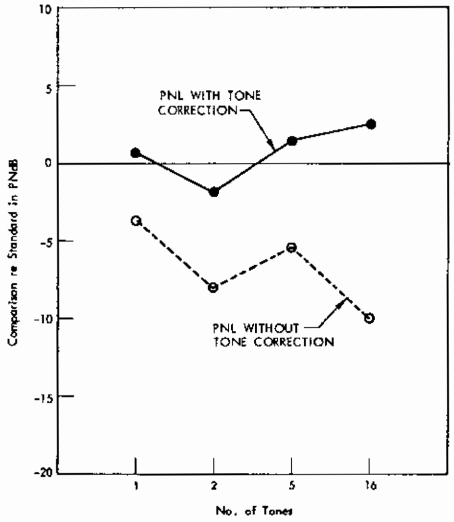

FIGURE 10. Judgments of equal noisiness of multiple tones in broadband noise (comparison) vs. broadband jet noise (standard).

carried out in which the tone-to-noise ratio and the duration of the stimuli were varied in the same test. Time patterns in this test were triangular to stimulate an aircraft flyover. Figure 11 shows some of the results of these tests as a function of tone-to-noise ratio. The results shown in Figure 11 are averages of data taken at 4, 12, and 32 sec duration and were obtained using the broadband jet noise employed in previous tests and a pure tone at 2000 Hz. The corrected perceived noise levels are again closer to the noisiness judgments than the uncorrected perceived noise levels. The duration of correction used in this test was 3 dB per doubling. The results for the 4-sec duration were not greatly different for the corrected or uncorrected values, because the short duration tends to cancel out the pure-tone component correction. However, for the long duration signals (those of 32 sec) and the large tone-to-noise ratios (25 dB), the results indicated the error would be almost 15 dB without the pure tone correction.

In summary, although we have shown only one type of tone and duration correction, there are others available (Little, 1961; Wells, 1967; Hargest and Pinker, 1967) which may comparably predict the noisiness of complex sounds.

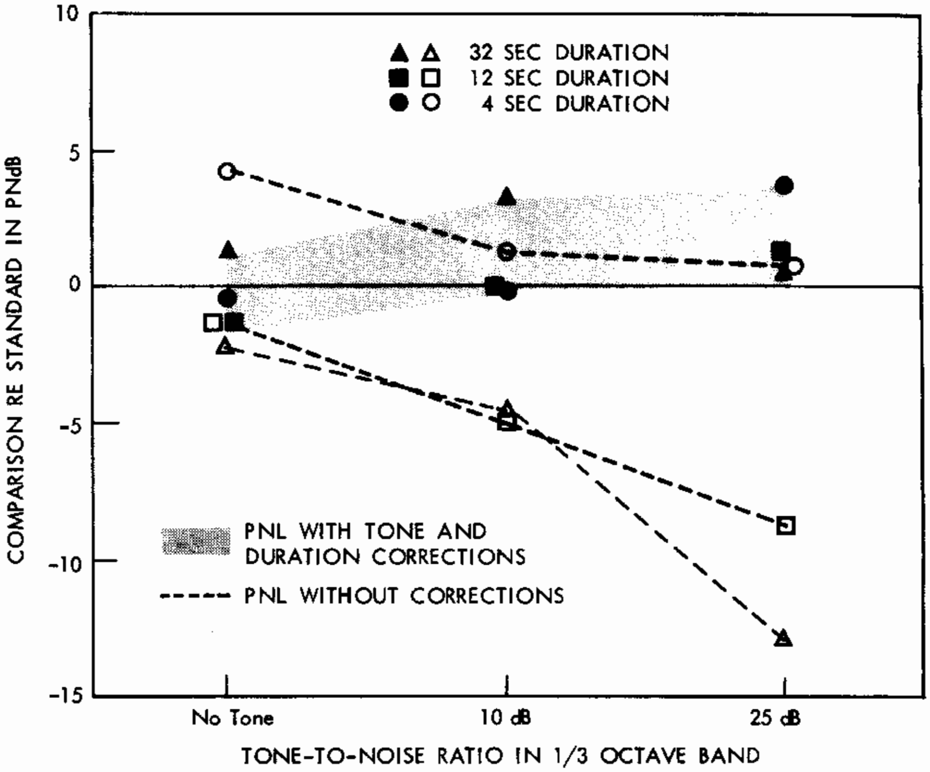

FIGURE 11. Judgments of equal noisiness for single tone in broadband jet noise of various durations (comparison) vs. broadband jet noise of 12-sec duration.

Although several conclusions can be drawn from the results presented here, I feel the most important general conclusion is that tone and duration corrections appear necessary and do a better job of predicting the noisiness of complex sounds with varying tones and duration than does perceived noise level alone. This does not mean that all questions have been answered. Additional work needs to be carried out to include other parameters such as Doppler shift and directivity effects to provide more realistic simulations of aircraft noise.

Acknowledgment

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References

HARGEST, T. J., and PINKER, R. A., The influence of added narrow band noisiness and tones on the subjective response to shaped "white" noise. *J. royal Aeronaut. Soc.*, **71.** 428-430 (1967).

KRYTER, K. D., The meaning and measurement of perceived noise level. *Noise Control,* **6,** 12-27 (1960). Addendum, *Noise Control,* **7,** 48 (1961).

KRYTER, K. D., PEARSONS, K. S., Judged noisiness of a band of random noise containing an audible pure tone. *J. acoust. Soc. Amer.,* **38,** 106-112 (1965).

KRYTER, K. D., and PEARSONS, K. S., Modification of Noy Tables. *J. acoust. Soc. Amer.,* **36,** 394-397 (1964).

KRYTER, K. D., and PEARSONS, K. S., Some effects of spectral content and duration on perceived noise level. *J. acoust. Soc. Amer.,* **35,** 886-883 (1963).

LITTLE, J. W., Human response to jet engine noise. *Noise Control,* **7,** 11-14 (1961).

PEARSONS, K. S., The effects of duration and background noise level on perceived noisiness. Technical Report FAA-ADS-78, April (1966).

PEARSONS, K. S., HORONJEFF, R. D., and BISHOP, D. E., The noisiness of tones plus noise. Technical Report, NASA 1-6364, September (1967).

WELLS, R. J., Recent research relative to perceived noise level. Presented at the 74th meeting of the Acoustical Society of America, November (1967).

Sonic Boom—A Community Study

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The impact of sonic boom on the community remains a key obstacle in the path of orderly development and use, over land, of commercial supersonic aircraft. National and international attention to this problem is reflected in numerous research programs (see Table 1) and experiences during the past decade. These have given us knowledge about the physical aspects of sonic boom and also some insight into the way sonic booms influence U.S. communities (Andrews Assoc. and Hudgins, Thompson, Ball, and Assoc., 1965). Such factors, as aircraft configuration and flight profile, which influence sonic boom are well understood and may be controlled or modified within limits to reduce the magnitude of sonic boom experienced on the ground. But community reactions to sonic booms are not as well understood; thus trying to predict the acceptability of overflights by supersonic aircraft by relating community reactions to specific sonic boom exposures is a matter of conjecture. Consequently, the problem of community response to sonic boom has emerged and has accompanied the technological developments which have made routine supersonic flight by manned aircraft possible. Although some theoretical and empirical approaches to the elimination of sonic boom have received attention in popular and technical news releases, first-generation supersonic transport aircraft, at least, will inevitably create sonic booms.

The national government recognizes that sonic boom will influence the operation of commercial supersonic aircraft, especially in planning flight profiles, route structures, and schedules. The government's concern that supersonic transport aircraft be operated in a manner acceptable to the general public has resulted in a large national research program of which the Oklahoma City sonic boom study was an integral part.

The stated objectives of the 26-week Oklahoma City study were to determine public reaction to sonic booms after extended exposure to the type overpressure levels and overflight frequencies that may be experienced by many communities if supersonic transport aircraft become commercially operational, and to determine the responses of structures to sonic boom overpressures, calculated at 1.5 to 2.0 pounds per square foot. Individual and community concern for effects of sonic boom exposures fall within the areas of possible personal harm or injury, damage to property, and intrusion into

TABLE 1. Summary of Operational Sonic Boom Research Programs. In these programs the sonic boom stimulus was generated by aircraft in supersonic flight except for the one laboratory study noted and some United Kingdom studies which used explosive charges to generate the shock wave. (JTF-2 refers to operational flight maneuvers of the Joint Task Force—2 near Tonopah, Nevada). B: Biological studies. P: Physical studies. S: Structural studies.

STUDY	PARTICIPATING AGENCIES	CALENDER YEAR																		
		50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68
WPAFB	USAF	◤																		
WPAFB-EDWARDS	USAF					◤														
WPAFB-EDWARDS	USAF						◤													
EGLIN AFB	USAF/USA							■												
WALLOPS ISLAND	USAF/NASA									■										
WALLOPS ISLAND	USN/NASA										■									
WPAFB	USAF										■									
NELLIS AFB	USAF/NASA											■								
NELLIS AFB	USAF/NASA											■	■							
EDWARDS AFB	USAF/NASA/FAA												◤							
EDWARDS AFB	USAF/NASA												◤							
ST. LOUIS	USAF/NASA/FAA												◢	◢						
CRACKERJACK	UK												◢	◢	◢					
LABORATORY STUDY	NASA												◢	◢						
CROSS COUNTRY SPEED RUN B-58	USAF													■						
WALLOPS ISLAND	USAF/NASA/USN													■						
EDWARDS AFB	USAF/NASA/FAA														■					
FIRECRACKER	UK														◢					
NAPOLEON	UK														◤					
YELLOWHAMMER	UK														◢					
OKLAHOMA CITY	USAF/NASA/FAA															■				
WHITE SANDS	USAF/FAA															■	■			
EDWARDS AFB	USAF/NASA															◤	◤			
CHICAGO	USAF/NASA																■			
JTF-2	USAF																■			
WESTMINSTER	UK																◢			
FRENCH	FRANCE																	◢		
EDWARDS	NASA/USAF																	■	■	

everyday living activities (Nixon and Hubbard, 1965). The procedures employed in the study were oriented to supplementing available information and obtaining new response data pertinent to these problem areas. From an operational standpoint the question was: What sonic boom levels and frequencies of occurrence would be acceptable to communities in our daily living environments?

Program Structure

Approach

The Oklahoma City area and surrounding communities were repeatedly exposed to sonic booms from a simulated regular schedule of supersonic transport overflights. Various effects on the community were thus ascertained. The stimulus exposure schedule is shown in Table 2. The scheduled overpressure levels were increased gradually from 1.0 to 1.5 psf and from one to eight booms per day over the first three weeks. The schedule of eight booms daily was maintained throughout the study at nominal overpressure levels of 1.5 psf from the third to the 19th weeks and 2.0 psf from the 19th week through the remainder of the study.

Major elements or data blocks in the program design were provided by: (1) precise measurement and analysis of sonic boom overpressures in various geographical locations in the area (Hilton et al., 1964); (2) an intensive public opinion survey (Borsky, 1965); (3) procedures for the acceptance of complaints by residents and the processing of alleged claims of damage to property; (4) observation and study of responses of structures and buildings (Andrews Assoc. et al., 1965); and (5) studies of meteorological effects on sonic boom propagation through the atmosphere (Kane and Palmer, 1964).

TABLE 2. Stimulus exposure schedule.

Study Period	*Number of Booms Daily*	*Nominal Overpressure (psf)*
0–3 weeks	Gradual increase from 1 to 8	Gradual increase from 1.0 to 1.5
4–19 weeks	8	1.5
19–26 weeks	8	2.0

Site

The Oklahoma City area was selected as the test site because it was characterized by the numerous features required at that time to satisfy the design objectives and to support the extensive flight program phase of the study. The area contained a large and diffuse population, which was familiar with both military and commercial aircraft operations, and which had had some prior experience with sonic booms. The area was also topographically desirable (flat), contained diversified types and ages of structures, and had variable weather conditions. Program overflights were conveniently staged from a nearby air base where ground support was readily available. Navigation was supported by local radio and radar units, and a local office which coordinated the overall study provided additional personnel and equipment as necessary.

Flight Track

A 100-nautical-mile flight track was established in the area in such a way as to cross densely-populated areas, both urban and rural, well established, and newly developed. The population areas were stratified according to lateral distance from the fixed flight track into different exposure groups for the personal interview survey which was to take place (Figure 1). Since overpressure levels decrease as a function of lateral distance the ground track, three different boom level exposure groups could be obtained by this stratification. The nominal intensities of sonic booms were approximately equal within each

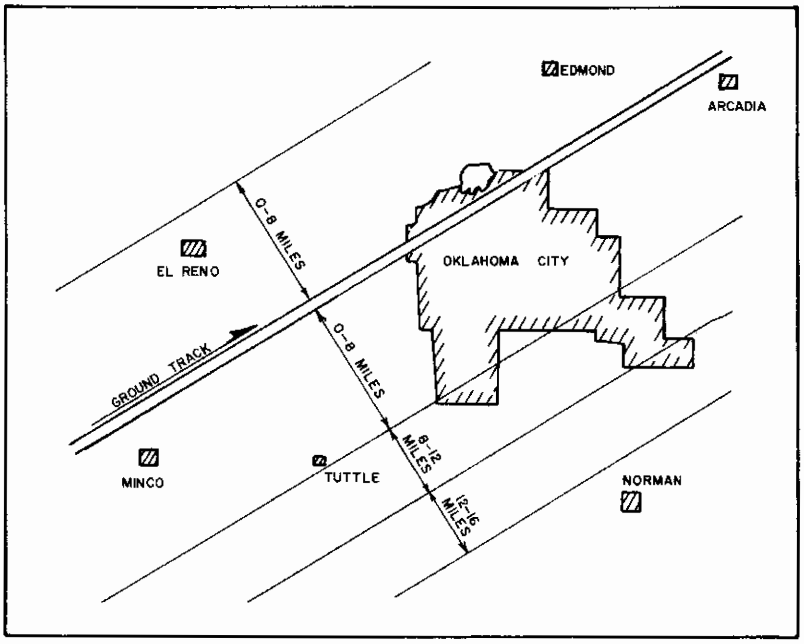

FIGURE 1. Unscaled, pictorial sketch of Oklahoma City area. Populated regions were stratified according to lateral distance from the ground track to provide different exposure levels for the personal interview survey. Residents within each distance group received essentially the same exposures. The most intense exposures occurred within the 0—8 mi regions and the least intense of the three within the 12—16 mi regions.

of the distance groups of 0-8 mi, 8-12 mi, and 12-16 mi so that individuals within each group experienced essentially the same exposures.

Aircraft

Sonic booms were generated by three types of fighter aircraft and one type of bomber aircraft operating in the altitude range of 21,000 to 50,000 feet and the Mach number range 1.2-2. All aircraft were positioned over the flight track by ground control procedures utilizing radar tracking. Aircraft position and ground velocity data were obtained from radar plots of each of the flights. Steady-level flight conditions of the aircraft at the desired Mach number and altitude were reached in the vicinity of Minco, Oklahoma and maintained across the test exposure area.

The simulated supersonic flight schedule was maintained for a period of six months. Eight sonic booms were generated daily during this period and the exact flight times, which were the same each day, were well publicized. The aircraft were clearly visible to residents on the ground during the supersonic runs.

Public Information Program

A sonic boom orientation and demonstration briefing, including exposure to eight sonic booms ranging from 1.0 to 2.0 psf, was presented to key officials and citizens of Oklahoma City and the surrounding area. This presentation, prior to the start of the flights, initiated the public information program maintained throughout the duration of the study. The Federal Aviation Agency (FAA) was publicized as sponsor of the effort and the study was explained to be an integral part of the national supersonic transport development project. The sonic boom phenomenon and details of the Oklahoma City study were described via local news media as well as in a pamphlet which was distributed widely throughout the area. The duration of the flights, the number and times of the daily overflights, telephone numbers to be called in the event of complaint or claim of alleged damage to property, as well as numerous other details, were all widely publicized. Government and aviation officials from all parts of the world visited the test area during the study. Local, national, and international news media reported frequently on the developments and progress in the Oklahoma City program.

Overpressure

Ground overpressure levels of the sonic booms were recorded at three main microphone locations at fixed stations directly under the flight track and at distances of 5-10 mi lateral to the ground track (Hilton et al., 1964) (Figure 2). Mobile van microphone stations recorded sonic booms at any desired location in the area. Various arrays and locations of microphones were used to obtain data for evaluating the variability of sonic boom pressure-time histories. A detailed log of each supersonic run and of the overpressure levels at the various recording stations was maintained.

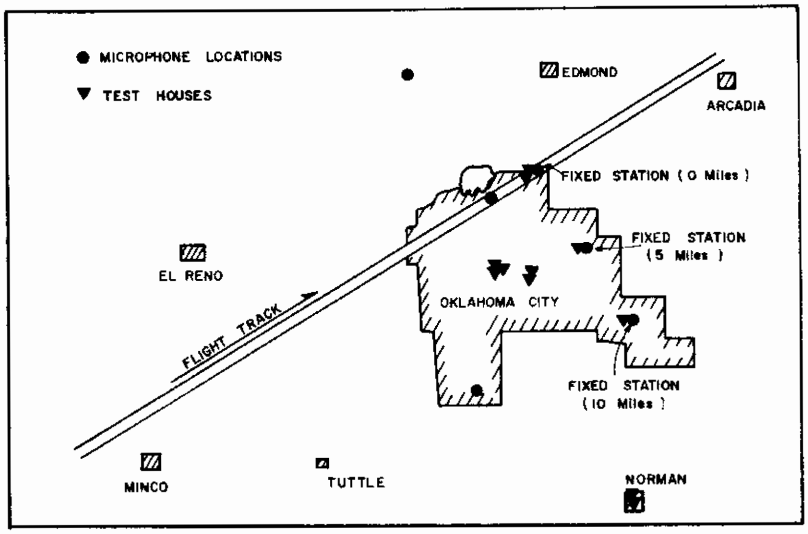

FIGURE 2. Sketch showing microphone and test house locations. Microphones at 0, 5, and 10 mi stations were fixed and all others were mobile. Test houses in Norman were outside the exposure area and served as controls.

Structures

Responses of structures and dwellings were studied in several test houses and related to the data through alleged claims of damage by local residents. (Andrews Assoc. et al., 1965). Five vacant houses were rented and instrumented to record responses of structures to sonic booms. Six occupied houses were also included in the response of structures sample; two of these were outside the sonic boom exposure area and served as control structures (Figure 2). Pre-exposure, extensive, and detailed inspections of each of the houses were documented. The four vacant houses were furnished with various household items such as mirrors, electric clocks, TV sets, electrical appliances, glassware, china, and the like and they were inspected after each boom. The occupied houses were inspected only every few days. A thorough final inspection of each house was made in the same manner as the initial inspections to provide, among other things, a summary of the conditions of each structure after six months' exposure to sonic booms.

Meteorology

Meteorological influences on sonic boom generation and propagation were also studied extensively (Kane and Palmer, 1964). Local weather information was provided by local airfield weather station within one hour of the times of all the supersonic flights. Data on temperature, pressure, speed of sound, humidity, wind velocity, and direction were provided at least up to the altitude of the test flight.

Personal Interview

A series of intensive personal interviews was obtained from adult residents from selected communities within the three exposure groups (Borsky, 1965). The same adult respondents were personally interviewed three different times during the six-month study program. The first interview occurred after 11 weeks of sonic boom exposure, the second after 19 weeks, and the last after the twenty-fifth week of booms. The interview was designed to appear as a broad survey of how people felt about the communities in which they lived. Queries were included about all kinds of local problems, as well as knowledge, beliefs, attitudes, and reactions to the sonic boom exposures. The real purpose of the study was not revealed to the interviewees at any time.

Complaint

A complaint center was operated to receive complaints and reports of alleged damage to property resulting from sonic booms. Complaints were recorded and tabulated as received, in such a way that the type or number of complaints received daily, or the cumulative total of complaints for any date, could be readily observed. In general, claims in excess of $7.50 were investigated and findings were submitted with recommendations for approval or disapproval to the government for adjudication. All decisions rendered against the claimants could be appealed.

Coordination

A program coordinator and his staff directed the overall study from an office in the test area. The many and varied activities of the numerous participating agencies were thus integrated into a composite design. This staff responded to special requests for information or assistance, and to local problems associated with the overflights and maintenance of the effort.

Data Accumulation, Evaluation and Discussion

During the period from February 3, through July 30, 1964, 253 sonic booms were generated over the test area on an eight-boom-per-day seven-days-a-week schedule. Findings in each of the four major technical areas involved in the study are reported in great detail in separate documents. Meteorological effects and details of dynamic responses of structures as investigated in the program are not included in our discussion because they do not relate directly to the question of the impact of sonic booms on the community, although the attitudes and beliefs of residents concerning the responses of their structures do indeed influence their general responses to boom exposures. Measurements of sonic boom ground overpressures are discussed in terms of the exposures experienced in the various stimulus zones in the communities as they relate to observed and measured subjective response. Activities of the complaint center and personal interview results will constitute the main portions of the remaining discussion.

Overpressure

Sonic boom pressure measurements were made both inside and outside the three test buildings located at measuring stations 0, 5, and 10 mi from the flight track. The outside microphones were shock mounted at ground level and the inside microphones were shock mounted at approximately 5 ft from the floor level near the center of the room. A special array of microphones was used for simultaneous measurement of sonic booms at several spaced distances parallel to and perpendicular to the flight track to measure variations of sonic boom in a very small area. Some of the results of the analysis of the sonic boom pressure measurements relate to the community reactions.

Wide variations in the pressure-time-histories of the sonic booms and in peak overpressure were measured (Figure 3A). These variations in the characteristics of the stimulus represent one factor that has not permitted a better relationship to be observed between stimulus value and human response in the operational situation. Although valid measurements of the physical stimulus were taken at the recording stations, defining the exact exposure of each respondent in his routine living situation is an impossible task. Measured sonic booms are customarily described in averages (mean or median) or nominal

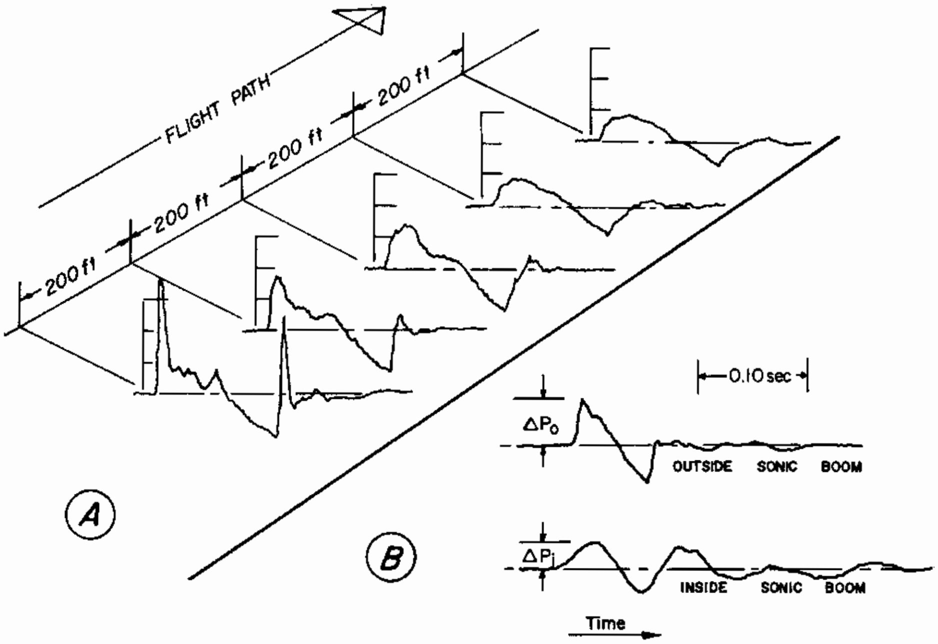

Figure 3. (A) Variations in pressure-time histories of a sonic boom. Pressure-time histories of a single sonic boom recorded by an array of five microphones positioned at 200-ft intervals parallel to the flight track are shown. Differences in features such as peak positive pressure and the rounded positive pulse in such short distances are considered significant. (B) Typical pressure signatures of a sonic boom recorded simultaneously outside and inside a structure. The outside boom reflects the typical N-wave pattern, while the inside signature is rounded off, lower in amplitude and longer in duration.

levels which are adequate for denoting the exposures to be related to the community responses.

Sonic booms inside a building were lower in amplitude and longer in duration than corresponding outside overpressures and were dominated by frequency components corresponding to the principal vibration modes of the building. Pressure levels in the range of frequencies 100 to 5000 Hz are about 40 dB below those in the range 0.1 to 5000 Hz. Thus an inside observer experiences strong pressure variations in the subaudible range and weak pressure variations in the audible range. Consequently, the inside sonic boom exposure is quite different from that experienced outside, and this difference must be considered in relating human response to sonic booms. Inside booms are accompanied by rattling and shaking of the structure's contents, and these motions are readily visible to the resident as well as audible. Typical representation of the same sonic boom recorded simultaneously from both positions is shown in Figure 3B. The outside pressure signature reflects the N-wave configuration whereas the inside signature is rounded off, lower in amplitude, and longer in duration.

Measured overpressures were slightly less than the nominal values contained in the study design, as shown in Table 3. These values represent those actually occurring in the communities. Nevertheless, this discussion will continue to refer to the nominal values of 1.5 and 2.0 psf as components of the study design.

TABLE 3. Measured median sonic boom overpressures (psf).

Interview Period	*0–8 Miles*	*8–12 Miles*	*12–16 Miles*
1	1.13 (1.5)*	0.8	0.65
2	1.23 (1.5)*	1.1	0.85
3	1.60 (2.0)*	1.3	1.00

* Nominal or predicted values.

Alleged Personal Injury

Sonic boom occurs suddenly and without warning, usually causing startle and possible concern about what happened. The nature of this stimulus, whether experienced outside as a sharp, loud boom, or inside as a longer boom which shakes and rattles the house and is accompanied by visual and vibrotactile cues, has contributed to the concern that sonic booms may directly harm or injure people. The widely-publicized claim, early in the study, of personal injury to a child emphasized the need to thoroughly investigate and document all reports of personal injury. A medical staff was available and on call in the event such complaints or claims were received.

The auditory mechanism is exceedingly sensitive to variations in pressure and is considered the system most susceptible to overexposure. Injury from pressure waves produced by blast appear first in the ear. However, both theoretical and empirical data demonstrate that pressure variations thousands of times greater than those experienced in communities are necessary to even approach the threshold of damage to the human ear (Table 4). Personnel involved in sonic boom research have repeatedly experienced overpressure levels in the range from 100 to 144 psf without ear protection with no ill effects. Community exposures rarely exceed 2 psf. Neither the Oklahoma City study nor the millions of other sonic boom exposures to date has demonstrated an adverse physiological effect or personal injury due to the sonic boom pressure wave (Nixon, 1965). Consequently, there is no direct physiological hazard to humans from exposure to sonic booms in view of the very low levels of pressure variations occurring there in contrast to the very intense levels required to even approach the threshold of damage to the ear. Data on long-term effects of sleep or rest interference by sonic booms during the night or day are not available from the operational situation. This was not identified as a particular problem in the six-month Oklahoma City Study.

TABLE 4. Observed and estimated responses of the auditory systems to sonic boom stimulation.

Nature of Auditory Response	*Sonic Boom Experience or Prediction*	
Rupture of the Tympanic Membrane	None Expected Below 720 PSF None Observed up to 144 PSF	
Aural Pain	None Observed up to 144 PSF	
Short Temporary Fullness, Tinnitus	Reported Above 95 PSF	
Hearing Loss: Permanent	None Expected from Frequency and Intensity of Boom Occurrence	
Hearing Loss: Temporary	None Measured 1. 3–4 Hrs Post-exposure up to 120 PSF. 2. Immediately After Boom up to 30 PSF.	
Stapedectomy	No Ill Effects Reported	After Booms up to 3.5 PSF
Hearing Aids	No Ill Effects Reported	

Complaints

A chronological history of complaints received at the complaint center from residents during the sonic boom study is clearly summarized in Figure 4. The total complaints received and the number of them alleging property damage were tabulated on a weekly basis for the six-month period. In general, the curve represents the high initial response expected at the introduction of overflights and some degree of adaptation with time and continuation of exposure. This area has a population of about 750,000 in its urban, suburban, and rural regions. As of March 1965, about eight months after termination of the overflights, about 15,100 complaints had been received, of which 9600 were alleged-damage claims. This reveals that about 5% of the area population actually submitted a complaint and a little more than 3% alleged property damage. In addition to the data on percentage of the population submitting complaints and claims, perhaps one of the most significant and interesting aspects of these data is represented by the irregularities or peaks which appear in the response curve, and the factors which caused or contributed to them.

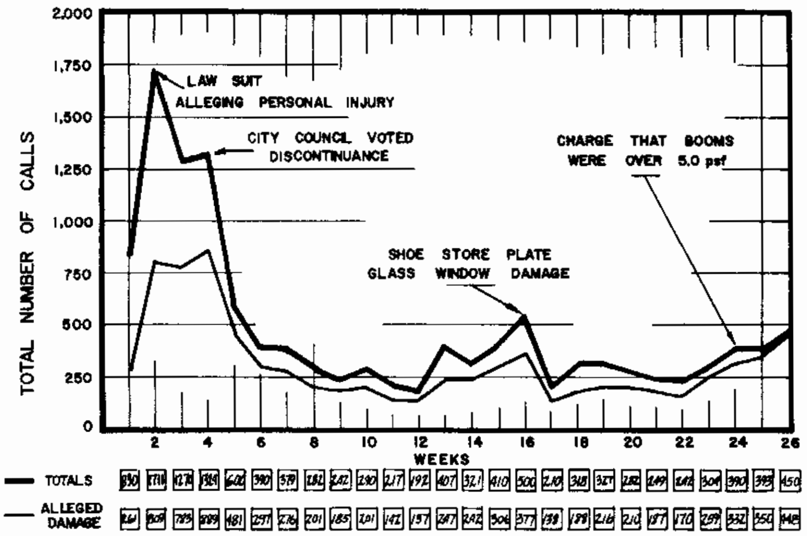

Figure 4. Chronological tabulation of complaints received during the Oklahoma City study. Note that peaks in the curve, representing increased community reaction, correspond to certain events which occurred in the community and appeared in the local or national news.

Each of the peaks in the curve can be related to some event or incident which received widespread coverage in the local news media. For example, the first and largest peak was associated with a publicized allegation of personal injury to a child induced by sonic boom; the second was associated with action by the City Council to have the study discontinued; another with alleged damage to a residential dwelling; and there were numerous incidents of a similar nature relating to the other peaks. This reveals that the observed community reactions were not necessarily directly related to overpressure level, but were strongly influenced by other factors. This finding is not encouraging for one wishing to estimate reactions to sonic boom based only upon overpressure level.

Personal Interview

A public opinion and reaction survey was completed in the Oklahoma City area during the course of the six-month sonic boom exposure period. Intensive personal interviews were conducted with almost 3000 adult local residents to determine their reactions to the sonic booms. Each person was interviewed at three different times during the study to observe if, and to what extent, their reactions and opinions might change with continued exposures and different level sonic booms (Figure 5). Control groups of about 200 additional respondents were interviewed during each of the second and third waves of sampling in order to measure the effects of prior interviews on the responses of the basic sample. The population sample selected included both urban and rural residents. Primary sample groups were selected to be different distances from the flight track in order to receive different level boom exposures. Careful records were kept of all complaints received by the local complaint center and Figure 5 shows some of this data compared with findings of the personal interview program.

The major public reactions to sonic booms during each of the interview waves are graphically summarized in Figure 6. Almost all respondents in each interview reported some interference with ordinary living activities. House shaking and rattling were almost always mentioned in the following order: (a) startle; (b) fear of booms; and (c) interference reported with sleep, rest, and conversation.

The personal interview study design was based upon extensive investigations of community reaction to aircraft noise and the personal interview experience of the St. Louis sonic boom study. The degrees of public reaction are these: some interference with routine living activities[1]; annoyance with the exposures; and action against sonic boom in the form of complaint. In this study, long range acceptability of sonic booms was of prime importance and techniques for measuring this reaction were included in the interview design.

Serious annoyance was reported by 37% of the respondents during the first interview, but this increased to 56% by the end of the six-month program. The

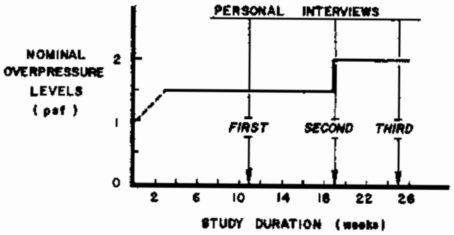

FIGURE 5. Schedule of personal interviews. Graphic representation of times during the study at which the three waves of personal interviews were conducted and the nominal overpressure levels programmed for the periods immediately prior to the various interviews.

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[1] Interference is typically reported as shaking of the house, startle, interruption of sleep, interference with conversation, rest, and relaxation.

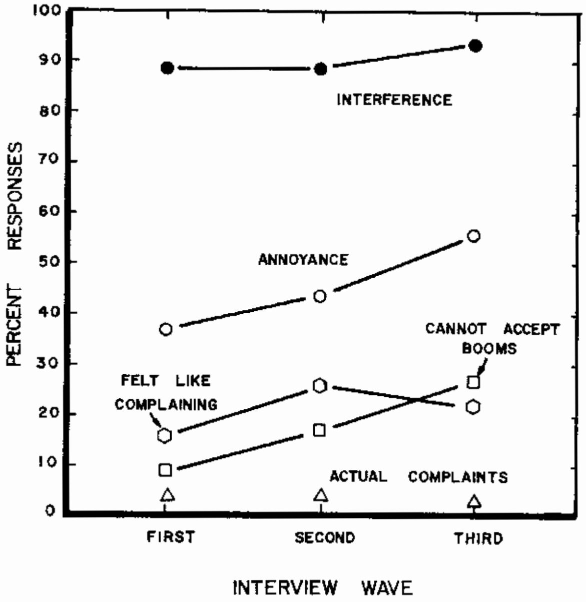

FIGURE 6. Overall community reactions. Summary of major public reactions during each of the three interview waves.

increase in annoyance appears to be primarily related to the increase in sonic boom intensity and to the continued, uninterrupted exposure. Median overpressure levels were 1.13 psf before the 37% response, 1.23 psf before the 44% response, and 1.60 psf before the 56% response.

The Oklahoma City area was characterized by a relatively low complaint potential; after six month's exposure 22% of the respondents felt like complaining while less than five percent actually registered a complaint with the authorities. This complaint level was influenced by various factors; such as the fact that 70% of the respondents did not know where to register a complaint, that most felt it would be futile and would do no good, and that the residents generally did little complaining about any serious local problem.

Of particular interest to the commercial supersonic transport was the long-range acceptability of daily and frequent sonic boom exposures. Respondents were asked whether or not they felt they could live with eight sonic booms each day for an indefinite period of time. At the end of the six months about one-fourth (27%) of all respondents felt they could not learn to accept the booms. This number rose from 9% during the first and 17% the second interviews to the 27%.

The reactions of these residents to local events and problems confronting them are influenced by many factors with different relationships in any given situation. Some reactions are determined by the stimulus or problem itself; others by knowledge, attitudes, and beliefs about the situation. Still other reactions are determined by factors totally unrelated to the question at hand. Each of these elements may have a positive or a negative influence on the reactions of a community. For example, an understanding of sonic boom; liking the community; believing that no property damage was caused by the booms; and high satisfaction with local government may contribute to high acceptability. The opposite feeling regarding each of these factors could contribute to feelings of annoyance and subsequent complaint. The manner in which a community is predisposed to these kinds of factors may largely determine or influence the amount of exposure that is acceptable to that area. Some of the factors in the Oklahoma City area which contributed to the community reactions produced by the long term study are mentioned below. Numerous other factors will necessarily be omitted in the interest of economy of space and time.

The residents had a very high attachment and satisfaction with Oklahoma City and were generally reluctant to complain about local problems. Most rated the community as an excellent or good place to live. Also, almost one third of all the residents had had personal or family connections with the aviation industry though this did not appear to bias their reactions since these were about the same as those of respondents who had no ties with the aviation industry.

Belief in having experienced property damage increased annoyance and complaint activity. Generally, individuals who ordinarily would not complain about interferences and annoyance readily complain when they believe their personal property has been damaged. It has usually been found in this and other studies that almost all complaints include a report of property damage. Only about one in five complainants actually submitted a formal request to the government for damage reimbursement.

Local and national publicity had stressed openly that this study was part of a test of human tolerance of sonic booms, and that a major consideration in any government support of supersonic transport development was whether the local populations would accept the booms.

Shortly after initiation of the overflights some groups of citizens organized in opposition to the program and attempted to stop the supersonic flights by legal means. These groups also sought to encourage complaints. Almost at the same time others urged acceptance of the boom study, and their actions tended to discourage complaints by local residents. Accounts of the activities and sentiments of these groups were well covered in the local news media.

The overall community reaction may be considered a composite of predisposing factors and stimulus exposure. Although it is recognized that factors in the environment, such as those mentioned above, do influence responses, it is the overall reaction of the residents in the sonic boom situation which actually indicates the degree of acceptability. In this study, residents experienced sonic booms in their homes, schools, churches, places of work and recreation, and other typical living situations, and their responses were measured. This type of "real-life" information (Figure 6) provides some basis for approaching such questions as: How much of a reaction, or what percentage of the population considering the boom unacceptable, is significant?

One means of evaluating long-term acceptability is to compare responses measured after subsequent increases in the duration of exposures. The major trend of the data on overall reactions (Figure 6) reflects a consistent increase in reaction with continuation of exposures. It is noted that overpressure levels of 1.13, 1.23, and 1.60 psf are associated with the three data points respectively on the absicissa. Consequently, there is no way to confidently extract that portion of unacceptability associated with level and that associated with duration. The practical result is clear, however, that the levels of unacceptability under this study design did increase, and about one quarter of the respondents indicated an inability to accept such exposures indefinitely.

No significant differences were found between the overall reactions of urban and of rural populations in the Oklahoma City area.

The influence of attitudes and beliefs on reactions is illustrated by considering the range of responses to some particular questions measured at the end of the six-month exposure. Figure 7 represents results in three response categories of those individuals with the most favorable attitudes and those with the least favorable attitudes toward the program. Annoyance ranged from 44% to 68%, desires to complain from 4% to 37%, and reported ability to accept eight daily booms indefinitely was 57% to 92%. The ranges of responses in these categories are attributable to the favorable (high) and unfavorable (low) attitudes of the respondents to the program, to the SST, and to the necessity of having sonic booms in the community.

The significance of the Oklahoma City study is enhanced by various features

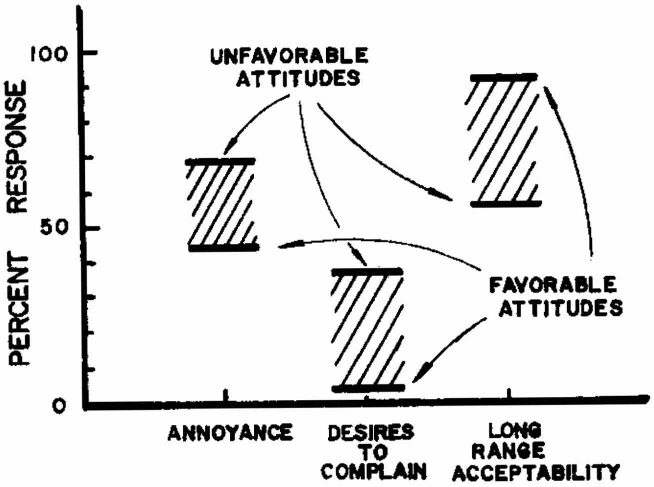

FIGURE 7. Range of reactions attributed to attitudes. Range of responses in three categories as influenced by attitudes at the end of the study. For example, about 92% of respondents with most favorable attitudes reported they could accept the sonic booms indefinitely whereas only about 57% of those with least favorable attitudes could do so.

incorporated for the first time into such a study, since many have not been duplicated, making this study the only source of certain information. These were the features:

(1) The study was sponsored by the Federal Aviation Agency and conducted as part of the supersonic transport development program. Thus the study was not biased by being a requirement for national defense, for which respondents are believed to be much more tolerant. The purpose of the study, to determine human tolerance to sonic booms, was widely publicized and most respondents reported an awareness of these facts.

(2) The duration of the study, and consequently the number of sonic booms, was rather extensive. The regular schedule of eight booms per day was consistently maintained over the program period. This remains as the most intensive community exposure to sonic booms on record.

(3) Typical structures within the active community were leased as test houses and extensively instrumented with engineering inspections made on a regular schedule. Some dwellings inhabited by local residents were also included as test structures and these were carefully inspected by engineers every few days to determine their response to the repeat sonic booms.

(4) A local office was available to receive comments and complaints concerning the program from the residents. Approximately 15,000 such calls and letters were received; about 2000 were repeat callers.

Summary

The Oklahoma study showed that community reaction to sonic boom is influenced by the stimulus, the immediate environment in which the sonic boom is experienced, and the numerous beliefs and attitudinal variables brought into the situations by the local residents. The wide variability associated with each of these factors has prevented the establishment of direct relationships among them and responses. Those individuals with the most favorable attitudes towards the program, its purpose and implications, reflected the greatest acceptability; the least acceptability came from those with opposite views.

Consistent with theoretical and empirical evaluations of sonic boom effects on people, there was no documented evidence of direct personal injury or adverse physiological effects of the boom exposures during the study.

Overall community reaction may be expected to reach a general level of response activity that is consistent with the stimulus so long as a significant change in the stimulus variables does not occur. However, any event commanding local attention may precipitate strong reaction when a community experiences a situation believed by them to be undesirable, even in residential areas considered passive or nonresponsive to local issues. This type of reaction is exceedingly difficult to predict with our present knowledge although contributing factors and causes can usually be clearly identified in retrospect.

Peak overpressure level, the unit typically used to describe sonic boom intensity, cannot be expected to describe adequately sonic boom exposures in terms of community reaction. In the laboratory, judgments of loudness or acceptability may be reliably related to descriptions of the stimulus which may involve appropriate characteristics of the pressure-time history of the boom. In time, advances in technology will surely allow sonic boom exposure criteria to be formulated. However, for our current understanding of the community situation, it is clear that the sociopsychological environments and experiences of the residents may exert more influence of response behavior than do variations in the stimulus exposure.

A level of acceptability of sonic boom exposure in the community was not established by the study. Degrees of acceptance and various factors which influenced them were measured under the various conditions which transpired. The significance of this information must be judged by the individual (or agency) users and the manner in which they wish to apply the information. Conclusions, per se, are not necessarily in order, but there is considerable basis for interpretation. The nature of the problem in the community is very complicated and there may be room for some controversy. Nevertheless, the program represents a relatively successful endeavor in a new field of human experience.

One final comment concerning this review. It should be clear that the establishment of acceptable community exposure criteria does not depend solely on the acquisition of additional technical knowledge. If we hope, in time, to be able to formulate sonic boom exposure criteria, this will require just as much a decision on the part of the community/society to accept certain exposures as it will require an increase in our knowledge. The measured and observed community responses represented in this discussion are considered valid for the period of time and conditions under which they were obtained. However, contemporary factors such as mobility in the community, technological advances, political climate, national and international affairs, as well as many other things, motivate beliefs, attitudes, and opinions that influence community response behavior at any one period of time. It is not known, or perhaps even to be expected, that community response to sonic boom is today what it may be at sometime in the future.

Bibliography

ANDREWS ASSOCIATES, INC., AND HUDGINS, THOMPSON, BALL AND ASSOCIATES, INC., Structural response to sonic booms. (Final Report), SST 65-1, (Supersonic Transport Development, FAA, Washington, D.C., Vol. 2, Appendix, February (1965).

BORSKY, P. N., Community reactions to sonic booms in the Oklahoma City area AMRL TR 65-37, February (1965).

HILTON, D. A., HUCKEL, V., STEINER, R., and MAGLIERI, D. J., Sonic boom exposures during FAA community response studies over a six-month period in the Oklahoma City area. NASA TN D-2539, December (1964).

KANE, E. J., and PALMER, T. Y., Meteorological aspects of the sonic boom. SRDS Report RD 64-160, September (1964).

NIXON, C. W., and HUBBARD, H. H., Results of USAF-NASA-FAA flight program to study community responses to sonic booms in the Greater St. Louis area. NASA Tech. Note No. D-2705 (1965).

NIXON, C. W., Human responses to sonic boom. *Aerospace Med.*, **36**, 399 (1965).

Sonic boom symposium. *J. acoust. Soc. Amer.*, **39**, Part 2, May (1966).

General Aircraft Noise

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Because of the increase in popularity of jet transport, complaints about noise from residents in communities surrounding airports are multiplying. In spite of acoustical advances in engine design, modified flight procedures, and design improvement in aircraft performance, the problem is becoming more serious because every year there are more and larger aircraft.

By 1975, in New York more than double the number of today's aircraft are expected to use that city's three commercial airports, even assuming a fourth is completed by then.

Many airports, particularly in the United States, are faced with organized legal action from airport neighborhoods. In some cases airport operations are seriously limited because of such factors as preferential runways and restrictions on night flying. Unfortunately, technical developments do not promise any reduction in total aircraft noise exposure in residential areas in the next decade.

Helicopters are also expected to multiply rapidly and eventually heliports may be located at many places throughout a large city. They too can be noisy but are not the subject of this paper.

The magnitude and complexities of relations between the air transport industry and communities around airports promise to become a major obstruction to the growth of civil aviation if noise exposure and the resulting effects on aircraft operations cannot be resolved.

Rating of Aircraft Noise

To facilitate the evaluation of aircraft noise in terms of the response of individuals to its general noisiness, and to provide legislative and regulatory bodies and manufacturers and aircraft operators with a common rating quantity, the perceived noise level (PNL) has been standardized internationally (ISO, 1966). The units of PNL are perceived noise decibels (PNdB). The perceived noise level converts the details of an aircraft noise spectrum at the instant of maximum intensity during a flyover into a single rating number. An approximate PNL may be obtained from a sound-level meter equipped with a special "N" network. A standard sound-level meter turned to the "A" scale is also a fair approximation to PNL, provided that, for the noise of existing jet, fixed-wing aircraft, we add about 13 dB to the meter reading and call the sum PNdB.

I emphasize that perceived aircraft noise levels in PNdB must not be compared directly with noise levels in dBA produced by steadily running machinery or by continuous surface traffic. The reasons are two-fold: First, the number of PNdB exceeds the number of dBA by many units; second, aircraft noise is rated at its maximum intensity, which, for each flyover, exists for only a second.

In assessing the total noise exposure in a neighborhood we must know the distribution of noise levels for the particular mix of aircraft involved, the length of time it takes for each plane to fly over and how many aircraft fly over in a given period of time. A revised version of ISO R-507 (1966), which combines these factors into a single set of contours for a neighborhood and yields a so-called "noise exposure index," is currently in preparation. Among other elements affecting a neighborhood's reaction to aircraft noise are the time of day, the attitude of the inhabitants toward air operations, and background noise.

Reaction of Individuals To Noise—How Much Aircraft Noise Is Too Much?

Large social surveys have been conducted in several American cities, in central London, and near the London airport. Those interviewed have lived both near to and far from military and civilian air bases. The results have revealed some interesting statistics. Figures 1 and 2 reveal some results of 1377

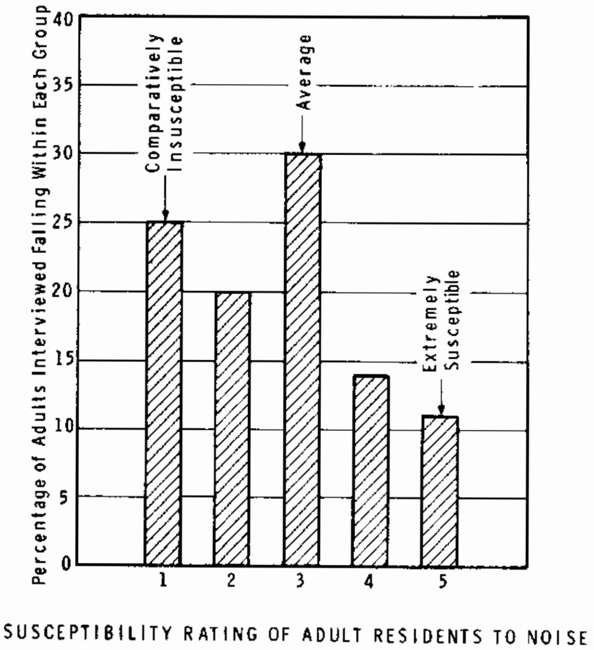

FIGURE 1. Bar graph showing the percentage of 1377 adults interviewed in depth in a 1961 Central London Survey for each of five categories of noise susceptibility rating. The susceptibility rating was derived from the answers to six questions on a 40-item questionnaire that evoked statements from the interviewees about their sensitivity to noise.

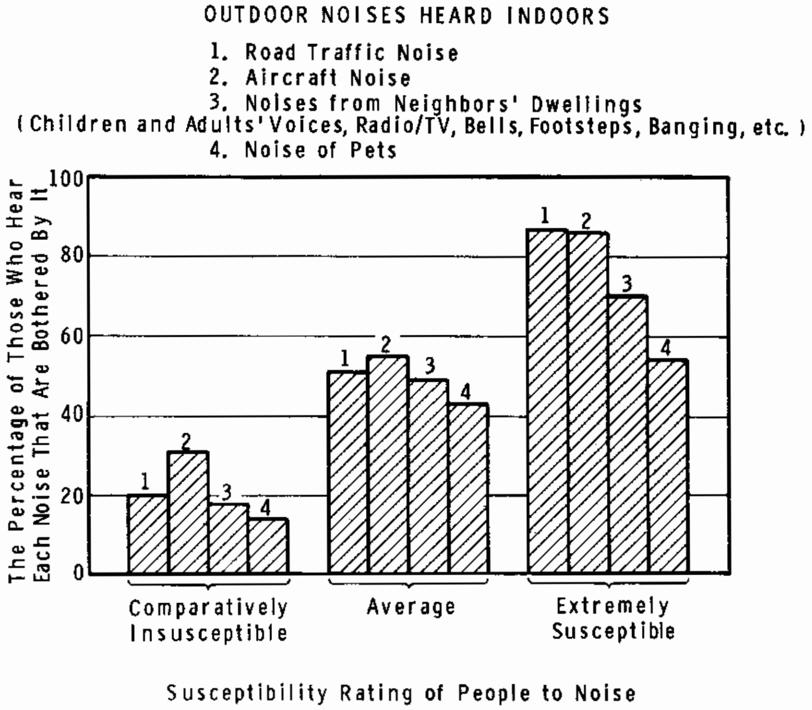

FIGURE 2. Bar graph showing the percentage of the 1377 adults interviewed in Central London who said they were bothered by particular outdoor noises that they heard when they were in their homes as related to their susceptibility rating to noise. The survey concluded that the extent of annoyance both with noise in general, and with particular noises, is very strongly related to the susceptibility rating. In fact, none of the physically measured noise parameters yielded any correlation between the noise that enters homes and the subjective reactions of Central London residents. By contrast, in a separate survey of residents within a 10-mile radius of the London (Heathrow) Airport, good correlations were found between measured aircraft noise parameters and subjective reactions.

interviews with adults in central London in 1961. Those interviewed were asked, as part of a 40-item questionnaire, these questions:

1. Does noise ever bother, annoy, or disturb you in any way?
2. When you hear the noise most annoying to you in your home do you feel very annoyed, moderately annoyed, a little annoyed, or not at all?
3. Would you say you are more sensitive or less sensitive than other people are to noise?
4. Is there too much or too little fuss made about noise nowadays?
5. How far would you agree that noise is one of the biggest nuisances of modern times?
6. Could you sum up your opinion by saying whether you find noise in general: very disturbing, disturbing, a little disturbing, not at all disturbing?

Each person's answers to these questions were rated on multipoint scales, and the average of the rating of numbers was used as a measure of each person's natural susceptibility to noise (Figure 1). We see that, measured by this scale, about one-quarter of those interviewed were comparatively insusceptible to their noise environment and about one-tenth were extremely susceptible. All those interviewed were also asked whether noises of various kinds, if heard in their homes, bothered them. Figure 2 shows a comparison of these responses with the noise susceptibility ratings. The correlation is high. For example, only 20% of those hearing a noise complained about it if they were within the "comparatively insusceptible" category. But, about 80% of those hearing traffic or aircraft noise complained about it if they were within the "extremely susceptible" category.

It seems that about one-fourth of the people can live relatively happily next to elevated train routes, truck routes, aircraft flight paths, or other very noisy activities, while about one-tenth are probably disturbed by almost any noise not of their own making. It was also found from the interviews that the highly susceptible people were dissatisfied with many other things in their environment. Similar results have been found in the United States.

One result from the central London study was that none of the physically measured noise parameters yielded any significant correlation between the noise that enters the home and the subjective reactions of the residents (McKennell and Hunt, 1966). By contrast, in separate surveys of residents within a 10-mile radius of the London (Heathrow) airport and around American airbases, good correlation has been found between maximum perceived noise levels and the subjective reactions of people to aircraft noise. These results lead to speculation that there may be less variation in the reaction of individuals to separated noise events, such as aircraft flyover noise, than to general background noise. If this line of speculation is correct, there is greater certainty of relieving annoyance by reducing aircraft noise (which is a series of discrete events) than by reducing traffic noise (which is steadier).

In both England and the United States, controlled attempts have been made, using subjects located near airports and subjects in laboratory situations, to determine a relation between outdoor perceived noise levels in PNdB (adjusted for the number of flights per day) and the "annoyance" of aircraft noise as judged by residents indoors under the flight paths near airports (Bishop, 1966; Robinson et al., 1963 and 1966). The tests were run in different ways so that the data are not directly comparable. Figure 3 gives my interpretation of the results from four such studies. The rather wide range of tolerances in the response averages of groups of individuals is illustrated by the height of the shaded region. It appears there is a significant degree of dissatisfaction with aircraft noise during daytime, whenever the average value of the maxima of aircraft flyover noise exceeds about 110 PNdB (assuming 20 to 40 flyovers each day during daytime hours). Studies also show that a significant degree of dissatisfaction occurs when the noise exceeds about 100 PNdB at night (10 p.m.–7 a.m.).

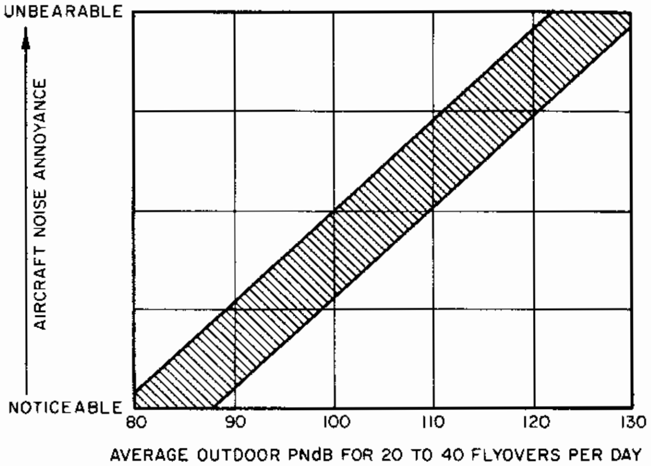

Figure 3. Approximate relation between the average of indoor judgments of the annoyance of aircraft flyover noise and the average of the maximum outdoor perceived noise levels, assuming 20 to 40 flyovers per day during daytime. In constructing this graph, the averages for the different groups were plotted. The spread in the averages is not necessarily capricious. A group's attitudes influence its judgments. Attitudes are often affected by fear of crashes, feelings of importance of the noise source, avoidability or necessity of the noise, feelings of considerateness of the airlines and airport to the group's welfare, overall satisfaction with the neighborhood they are living in and so forth.

Takeoff and Landing Profiles and Associated Perceived Noise Levels

Jet aircraft produce noise on both takeoff and landing.[1] Takeoff noise differs in character from landing noise because on takeoff engine thrust is high and the height over a neighborhood at 3.5 mi from start of brake release is likely to be 600-1200 ft. When landing, the height, in present operating practice, is likely to be about 300 ft at the same place in the neighborhood. Although engine thrust is lower, the tilt of the aircraft and the shorter distance causes the whine of the intake compressors to be much more annoying on landing than takeoff. On balance, the landing noise for most turbo-fan aircraft is at least as annoying as the takeoff noise; in many instances it is more annoying.

Figure 4 shows a comparison of takeoff flight profiles and perceived noise levels PNL for a medium 3-engine aircraft and a large 4-engine aircraft fully loaded. At 18,000 ft (3.5 mi.) from brake release, the PNL beneath the flight path for the 3-engine aircraft is about 110 PNdB while for the 4-engine aircraft it is about 125 PNdB on a standard day. On a hot day the PNL will be as much as 4 dB higher because of reduced rate of climb.

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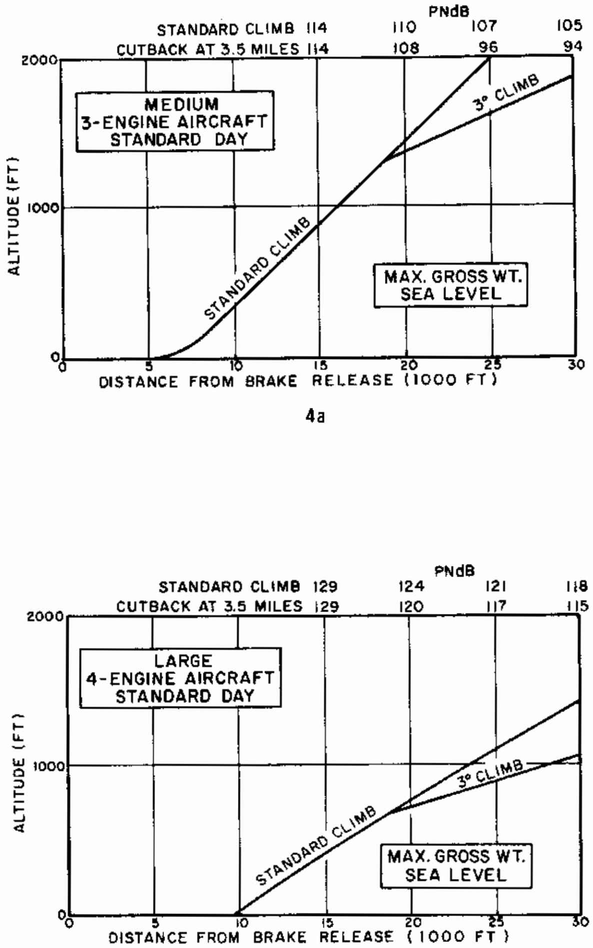
[1] Large, J. B., and Mangiarotty, R. A., Some aspects of the development of quieter aircraft, Paper presented at Inter. Conf. Reduction of Noise and Disturbance caused by Civil Aircraft, London, November 1966.



4a

4b

FIGURE 4. (a) Typical take-off flight profile for medium-range 3-engine turbo-fan aircraft (1968) in standard and 3° climb attitude on a standard day. (b) Same for long-range 4-engine turbo-fan aircraft (1968). The associated perceived noise levels directly under the flight path are given at the top of the graphs.

For large aircraft, a cutback in power as far as possible to the thrust necessary to retain a safe rate of climb (3° rate) reduces the PNL by about 4 PNdB.

Figure 5 gives the flight profile and a comparison of PNL for these same aircraft on landing. The data are shown for a standard glide slope of 3° and normal approach speed. Higher glide-slope angles will reduce the noise but are seldom used by pilots for reasons of safety with present aircraft.

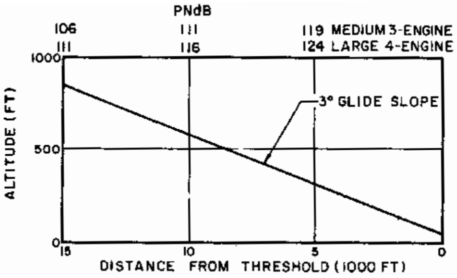


FIGURE 5. Standard 3° glide-slope approach. The perceived noise levels directly under the flight path for medium-range 3-engine and long-range 4-engine turbo-fan aircraft are shown along the top edge of the graph.

Legal Considerations With Respect To Aircraft Noise

The Constitution of the United States gives Congress the power to regulate air traffic. Congress in turn has created the Federal Aviation Administration, within the Department of Transportation, to certify (1) the air-worthiness of individual aircraft, and (2) the adequacy of the airline plans to operate individual aircraft from particular airports.

In other words, the aircraft must be safe and each airport into which it operates must meet federal safety requirements for that particular aircraft. The FAA controls the movement of aircraft throughout the U.S. and the public must permit overflights above 1000 ft and at lower altitudes "when necessary for takeoff or landing of aircraft" (Office of Science and Technology, 1966, pp. 132-142).

Except for two airports serving Washington, D.C., all U.S. airports are owned, developed, and operated by local governments, companies, or authorities.

But the public has some property rights in airspace. The Fifth Amendment of the Constitution prohibits the taking of private property for public use without just compensation. Accordingly, in the case of *Causby* v. *the United States*, the U.S. was held liable for the taking of a portion of a farm by overflights of military aircraft at such low altitudes and in such numbers and frequency that the beneficial use of the farm was destroyed.[2]

Further, the Fourteenth Amendment of the Constitution states that no state or state agency shall deprive any person of property without due process of law. Accordingly, in the case of *Griggs* v. *the United States* the airport operator was held liable to a property owner for the taking of an avigation easement[3] over his land because of low and frequent overflights of commercial aircraft.[4] But the Federal Government, which controls overflights, and the airlines who created the disturbance, were not held liable.

Viewed from the perspective of the number of lives affected, the noise problem is clearly sociological and requires an integrated approach to its solution rather than the haphazard one of adjusting individual controversies on

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[2] 328 U. S. 256, 260-1, 90L. ed. 1206, 1210, 66S. Ct. 1062, 1065 (1946).

[3] An avigation easement permits free flights over the land in question, even if the flights are so low and so frequent as to amout to a taking of the property.

[4] 369 U. S. 84 7L. ed. 2nd 585, 82S. Ct. 531 (1962).

a legal case-by-case basis (Office of Science and Technology, 1966, pp. 118-131).

Methods for Noise Control

The noise that residents of a neighborhood experience from aircraft flyovers may be reduced in varying amounts by a variety of methods:

1. Reduce the noise power generated by aircraft when the engines are operated at full thrust.
2. Require aircraft to reduce thrust and climb at a lower rate when above some minimum safe altitude and when over inhabited areas.
3. Turn aircraft away from residential areas during the climb-out phase of takeoff.
4. Institute preferential runway systems to direct aircraft away from communities.
5. Limit the number of operations and maintenance runups during nighttime hours (e.g., 11 p.m.-7 a.m.).
6. Increase the rate of climb or descent upon takeoff or landing.
7. Construct runways in directions away from noise sensitive areas.
8. Soundproof and air-condition residences.

The Federal Government has instituted a coordinated research and development program with leading engine manufacturers. By about 1973 this program is expected to produce a new engine with substantially less radiated noise power than today (NASA, FAA and USAF).

At a recent hearing in Boston, conducted by Edward Kennedy, Senator from Massachusetts, the government and the air industry presented testimony which yielded the opinion that by 1973 aircraft could be built that would be 7 to 20 PNdB quieter during flyover than today's noisiest turbo-fan aircraft. It was also suggested that by 1970 present-day turbo-fan aircraft might be able to be retrofitted to produce noise reductions of 1 or 2 PNdB—a difference, though, of little significance.

New techniques of noise reduction and the engines will be expensive and we can expect they will go unused unless maximum permissible noise levels are established. Under present law the Federal Aviation Administration has no power to establish noise criteria and standards or to certificate aircraft on the basis of noise characteristics. The absence of this power constitutes a glaring loophole in the present Federal regulatory system of air commerce control. Legislation is now pending in Congress that could correct this situation.[5]

Two, large city airport operators have noise regulations for jet aircraft which

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[5] Under a 1968 law (PL 90-411) the FAA is now directed to set noise standards for all types of aircraft. These standards are to be used as a basis for certification of new aircraft. On January 6, 1969, the FAA proposed new rules that would specify maximum legal sound levels for takeoff and landing, under the flight path and to the sides of the runway. These permissable levels vary according to the weight of the aircraft. The

users of their airports are required to obey. At John F. Kennedy International Airport in New York the permissible limit for takeoffs over neighborhoods during daytime is 112 PNdB; at night the jets are usually required to take off over water. The noise levels are monitored by black boxes at points on the edges of the community that are extensions of the centerline of each runway.

At London's Heathrow airport, a daytime maximum noise level of 110 PNdB is permitted at mobile monitoring points (for each runway) within the first major residential area overflown after takeoff. A level of 102 PNdB is the nighttime noise limit. Both airports indicate general compliance with these regulations by the airlines. In no U.S. cities other than New York are takeoff noise limits known to be in effect. But to the best of our knowledge, there are no limits on landing noise at any airport, even though the perceived noise levels are likely to be comparable to those for takeoff.

The FAA concluded from a series of measurements made at Kennedy International Airport in the summer of 1964 that the aircraft of five major airlines, operating in accordance with their specified company procedures following takeoff, produced, on the average, about 5 PNdB more noise than they would have produced if they were to follow a suggested FAA "minimum noise flight procedure" (Off. of Sc. and Tech., 1966, pp. 93-98). The FAA stated that its proposed procedure does

> not result, in practice, in any material infringement of any minimum safety standards . . . . [Its procedure is] not too demanding or exacting in terms of piloting ability and does not involve excessive workloads. . . . Control of the flight path in both segments is considered to be well within the capability expected of a professional pilot licensed on the type of aircraft.

Pilots are apparently reluctant to use the suggested FAA procedure for the Air Line Pilots Association (ALPA) maintains the following:

> A large reduction in noise level implies a large reduction in thrust which, in turn, means a substantial engine response time. In the event that an evasive maneuver were required, the engine response time would be detrimental to the success of this maneuver. The consequences of an engine failure in this reduced thrust condition can be hazardous [Off. of Sc. and Tech., 1966, pp. 102-105].

The FAA also stated this:

> We believe that the noise levels downstream from the [noise] monitoring point should be progressively less as the aircraft overfly the community. Some procedures used today impose higher noise levels [on the community] downstream than the levels recorded at the beginning of a noise sensitive area [Off. of Sc. and Tech., 1966, pp. 93-98].

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new regulations do not apply to jet planes now in service. This approach will lead to substantial noise abatement after about 15 years. Airport neighbors will view this program as inadequate; air travelers and airline operators will view this rule favorably because fares will not be affected and costs of retrofitting aircraft will be avoided. The FAA promises to study the costs and feasibility of requiring aircraft now in service to meet these rules.

The reason for the higher levels downstream is that the monitoring procedure is based on a measurement at a single point for each runway. It is possible for the pilot to cutback engine thrust only when the aircraft is near one of the monitoring microphones used at the edges of the communities around the airport. Additional monitoring meters placed farther out in the neighborhoods, accompanied by lower required noise limits at progressively greater distances, would result in reduced noise levels for many people.

Many airports are so situated that greater population densities exist in some directions from the airport than in others. The FAA consistently prescribes runway usage and arranges flight patterns that avoid densely populated areas. For example, today, at Kennedy airport, whose southwest edge is bounded by the ocean, almost all operations requiring landings on runways 13R and 13L are accomplished over the water or over the less densely populated areas along the shore line of Jamaica Bay. Prior to adoption of this procedure, some 225,000 people were exposed to high noise levels from landing operations on these runways (Off. of Sc. and Tech., 1966, pp. 86-92). The present major flight paths are shown in Figure 6.

To minimize takeoff noise exposure over the heavily populated areas to the east of London's Heathrow airport, a western traffic flow is usually selected, even if there is a tail wind component, provided the wind does not exceed a maximum permissible strength. The control tower also selects a landing

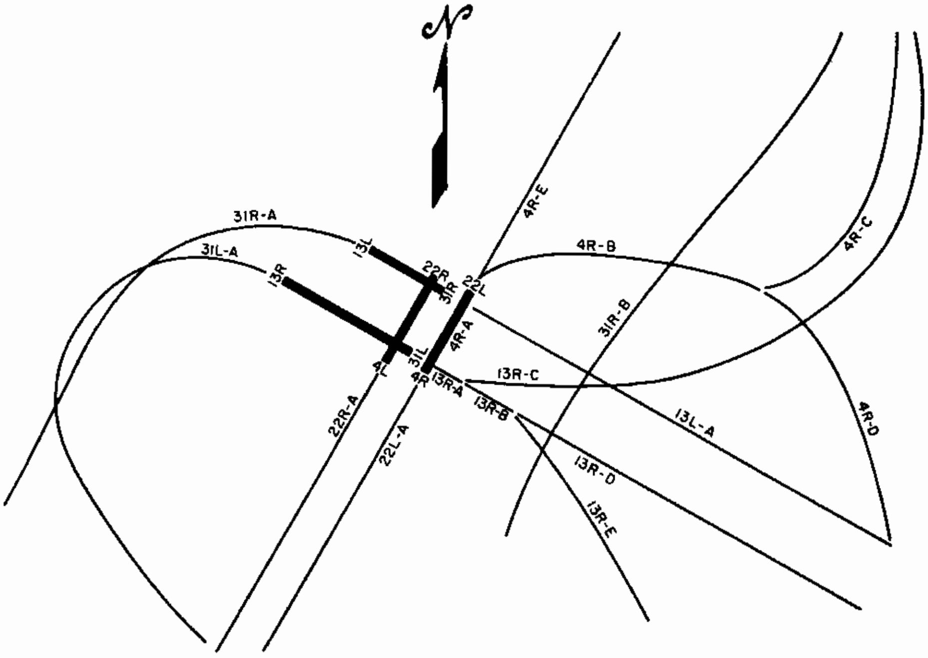

FIGURE 6. Current major flight paths for John F. Kennedy International Airport in New York.

runway whose threshold is farthest away from the built-up area, wind conditions permitting.

It is a complex matter to estimate a neighborhood's reaction to noise of operations to and from an airport. A procedure is however available for estimating total noise exposure of residents of communities surrounding an airport (Bolt Beranek and Newman Inc., 1964).[6] This procedure requires detailed estimates of takeoff and landing information on each runway, including the types, noise ratings, and average number of movements of aircraft during nighttime (10 p.m.–7 a.m.) and daytime (7 a.m.–10 p.m.) periods.

This information is assembled and handled according to charts and formulas. The result is that the area around an airport can be divided into several zones of noisiness, say A, B, and C (Figure. 7). Such zones can be used in future land-use planning, e.g., prohibit housing in zones B and C. But for buildings already existing in zones B and C, the necessary sound attenuations in PNdB (or dBA) for roof, walls, windows, and doors necessary for the inhabitants' indoor comfort are determined according to need (see Tables 1 and 2) (Teplitzky and Hirtle, 1968). The sound attenuation requirements presented in these tables are intended as a guide for general planning and cost estimating; details have to be worked out for each individual house. The specified sound attenuation values are based on the median of acceptability judgments of a large number of persons. Noise sensitive people might prefer better buildings, while insensitive people would probably accept less expensive structures.

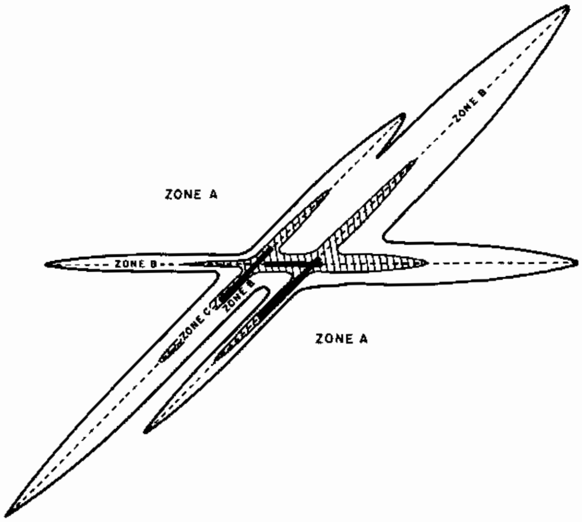

FIGURE 7. Regions of noise exposure around an airport with takeoff and approach flight paths. Zone A: Aircraft noise may not constitute a problem for many types of buildings. Zone B: Aircraft noise in buildings in this zone may be a problem to occupants. Zone C: Occupants of buildings in this zone will find aircraft noise a severe problem.

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[6] Also see papers presented at the Inter. Conf. on Reduction of Noise and Disturbance caused by Civil Aircraft, London, Nov. 22-30, 1966.

Table 1. Required sound isolation ratings for several building types (Teplitzky and Hirtle, 1968)

Type of Space	*Noise Zones*		
	A	*B*	*C*
Restaurants	N	6	8
Sports facilities indoors	N	5	7
Offices—secretarial	N	4	6
Offices—drafting	N	6	7
Offices—semiprivate, clerical	N	8	9
Residences	N	4	6
Hotels and motels	N	4	6

* N = normal building construction.
NOTE: Numbers are sound isolation ratings of Table 2.

Table 2. Typical sound isolation ratings for aircraft noise provided by typical construction materials (Teplitzky and Hirtle, 1968).

Construction Materials	*Sound Isolation Ratings*
Types of Construction	
Conventional Lightweight	
Windows Open	1—2
Windows Closed	3—4
¼ in. Glass Sealed in Place	4—5
Walls and Roof	
Weighing 20–40 lbs/sq ft	5—6
Weighing 40–80 lbs/sq ft	6—7
Windows*	
⅛ in. Glass in Double-Hung Wood Frame	0.5—1.5
¼ in. Plate Glass, Sealed in Place	2—3
Double Windows in Aluminum Frame, Glass Panels Set in Neoprene, ¼ in. Gaskets, $\frac{7}{32}$ in. Panes, 3¾ in. Airspace	5—6
Exterior Walls	
Wood Sheathing or Stucco, etc., on 2 × 4 Studs	
½ in. Plaster Board Interior Wall	2.5—3.5
⅞ in. Plaster Interior Wall	3.5—4.5
4½ in. Brick or 6 to 8 in. Lightweight Concrete Block	4.5—5.5
9 in. Brick Wall	6—7
Roofs	
Built-Up Roofing on 1 in. Wood Decking, ½ in. Plaster Board on 2 × 8 Joists	1.5—2.5
Built-Up Roofing on 1 in. Decking, ⅞ in. Plaster on 2 × 8 Joists	3.5—4.5
Built-Up Roofing or Shingles on Wood Sheathing, Ventilated Attic Space, ½ in. Plaster Board Ceiling	5.5—6.5
Built-Up Roofing or Shingles on Wooding Sheathing, Ventilated Attic Space, ⅞ in. Plaster Ceiling	6—7
Doors	
Noise Zone B Entrance Doors for Residences are 1¾ in. Solid Core Exterior Wood Doors with Heavy-Duty Weather Stripping.	
Noise Zone C, Same as for B, and Add Separate Storm Door with Weather Stripping.	

* These values are to be used in buildings that have window area exceeding 10% of wall area.

For the next decade at airports where aircraft noise limits are already in effect, modification of building structure accompanied by year-round air-conditioning promises to be almost the only solution to an owner's demand for substantially quieter indoor life. Obviously outdoor spaces will always be exposed to the noise of aircraft flyovers (Bolt Beranek and Newman, 1967).

Recommended Government Actions

The most urgently needed Federal action is to explore means and to pursue those means vigorously for reducing the noise levels of existing aircraft. The problem has four parts: (1) technical feasibility, (2) costs, (3) public need relative to costs, and (4) alternate ways to finance costs.

A principal factor mitigating against action is cost: Who is to pay the piper? To date there has been no objective economic evaluation of the benefits and costs of reducing noise in order to allocate the burden properly. But, at the moment, the specter of billions of dollars being spent by the Federal government has effectively put the brakes on necessary action.

The National Aeronautics and Space Administration (NASA) and the FAA should increase their expenditures for (a) better understanding of the amount of noise acceptable to people, and (b) quieting engines and aircraft. In Fiscal Year 1968, NASA's and FAA's expenditures were about one tenth lower than one study shows should be spent for research and development on aircraft noise in each of the next four fiscal years.

Better ways for reducing noise from aircraft inside homes should be developed. The Federal Housing Administration has announced that it plans to modify several homes in each of three or four cities to demonstrate techniques and costs of using simple modifications in windows and doors. At the heart of this problem is the need for economical air conditioning in closed houses. At present most people residing near airports will not be able to lessen the noise in their homes because to do so windows must be closed and the cost of air conditioning is too great.

In England a program to modify a few rooms in each house in a specified noise zone by use of matching homeowner-government funding has been tried. The program has apparently failed however because the homes were not comfortable after modifications because comfortable ventilation and cooling were lacking.

Money is needed for research and development of economical, noise-reducing building components and low-cost air-conditioning equipment. To the present the Federal Housing Authority (FHA) has not supported such research, feeling that the building industry should bear the costs. For their part, the building industry, fractionated as it is, says it does not now see sufficient market for noise-excluding products to justify research and development money. Obviously, government support is needed to establish design guidelines for noise-excluding structures which can then be built by industry or local carpenters.

Conclusions

In conclusion, I wish to emphasize that aircraft noise will not go away by itself. In the next 10 to 15 years the only possible, significant alleviation of annoyance will be through improved flight procedures and substantial modification of houses to exclude exterior noise.

Assuming that noise standards are eventually legislated, we must begin now to develop quieter aircraft engines.[7] Also, the Government must fund studies of means for modifying existing houses at reasonable cost to exclude aircraft noise.

Bibliography

BISHOP, D. E., Judgments of the relative and absolute acceptability of aircraft noise. *J. acoust. Soc. Amer.* **40**, 108-122 (1966).

BOLT BERANEK AND NEWMAN INC., Land use planning relating to aircraft noise. Federal Aviation Agency, Wash., D. C., October (1964).

BOLT BERANEK AND NEWMAN INC., A study—insulating houses for aircraft noise. U.S. Dept. of Housing and Urban Development, Wash., D. C. (1967). (55¢, Supt. of Documents, U.S. Govt. Printing Off., Washington, D. C. 20402).

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION, Procedure for describing aircraft noise around an airport. ISO Recommendation R-507, November 15 (1966).

MCKENNELL, A. C., and HUNT, A. E., Noise annoyance in central London. Rep. SS 332, Bldg. Res. Station, Garston, Watford, Herts, England, March (1966).

OFFICE OF SCIENCE AND TECHNOLOGY, Alleviation of jet aircraft noise near airports. Exec. Off. of the President, Wash., D. C., March (1966) ($1.25, Supt. of Documents, U.S. Govt. Printing Off., Washington, D.C. 20402).

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[7] See footnote 5.

Damage Experience

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The title of this talk, "Damage Experience," may be a misnomer. A more appropriate title might be "Sonic Boom Claims Experience," since that subject falls directly within the responsibility of the Air Force Judge Advocate General's Department, of which I am a member. A better reason, however, for referring to claims rather than damage experience, is that no one can say with certainty, in all cases, what the relationship is between claims and damage.

A *claim* is defined as a specific written, monetary demand upon the Air Force; I can, and will, tell you what I can about how many claims have been received, the type and amount of damage alleged, and the disposition of these claims by the Air Force. I can't tell you how many, or which of these claims may have been in fact caused entirely as a result of Air Force supersonic activities. There are many reasons for this difficulty. One reason is that sonic boom damage is often discovered rather than seen to have happened. Though occasionally an eyewitness may see a window break or observe a plaster ceiling fall, most sonic boom damage is found either (1) after the claimant hears the boom and begins inspecting his property thoroughly for damage (often for the first time in years), or (2) when the claimant suddenly perceives damage which may have existed for a considerable time and then searches his memory for a recent event which he feels could have caused the damage. In the latter instance, the damage could well have existed for years and sometimes claims investigators, upon close inspection, find dirt or even paint in the newly found glass or plaster cracks. However, the unperceptive property owner will often be unconvinced and will continue to indignantly blame the sonic boom which recently startled or annoyed him. Indeed, we suspect the subjective attitude of the property owner toward the Government, toward aircraft and other items disturbing his tranquil existence has an effect upon his propensity to make claims for progressive property damage which other, less affected, property owners might attribute to natural effects.

We have found, in processing claims, that mysterious damage of unknown or unexplained origin will frequently be blamed on sonic booms if a boom has occurred anytime near the time of damage (and sometimes even if it has not). Fires resulting from unexplained causes or possible electrical short circuits, dried up wells, wilted vegetation, damage to television components, and many other incidents have been attributed to sonic booms in the past. When such a damage condition or event occurs simultaneously, or very nearly so, with a sonic boom there is certainly a strong cause and effect inference in the mind of the observer. It is a certainty, for example, that during the early evening hours in any city of one million population, a certain number of television sets will be operating and will inevitably become defective during that period. If a sonic boom occurs about the time a set goes off or becomes weakened, it is difficult to convince the owner that the sonic boom was not at fault even though we know the boom would not have caused the damage. Since many of the supersonic B-58 bomb-scoring runs over midwestern cities in the early 1960s were flown in the early evening hours, a predictable number of claims arose as a result.

Naturally, sonic boom damage claims cannot be processed with the test-tube-like precision with which one may conduct a scientific test or experiment. Only the claimant (if anyone) knows what his property looked like prior to the sonic boom. Often, only the claimant is able to furnish the circumstances under which the damage was discovered. Usually, only the claimant or those in his immediate vicinity are able to describe the intensity of the sonic boom at that particular point. From these circumstances, it may be seen that much of the processing of a sonic boom claim involves consideration of the subjective opinions and observations of persons whose impartiality and legal credibility are always in question. The Air Force, in its investigation, must identify the aircraft as of likely Air Force origin and in some cases must utilize the services of an expert, such as an engineer, to ascertain the cause of damages. In addition, policy guidance has been formulated by the Air Force based upon the results of scientific tests to advise investigators and claimants generally as to what damage may ordinarily be caused by a sonic boom.

The Air Force system for processing sonic boom damage claims proceeds as follows: A complaint of damage may be presented in any manner to the nearest Air Force base claims office. There are approximately 140 scattered throughout the United States. An Air Force claims officer, who must be a lawyer, will then send the claimant claims forms and instructions on presenting a claim and also conduct, or supervise, an investigation into the cause of damage. It has been Air Force experience that out of approximately every three persons complaining of damage and who have been sent the claims forms, only one will actually present a claim. No doubt the small amount of damage sometimes involved and the difficulty in obtaining estimates and evidence to support the claim will discourage some people from presenting a claim. Another reason for nonfiling may be found in the statement of Air Force policy relating to sonic boom damage which is printed on the back of sonic boom property damage claims forms. That policy applies to sonic booms created by aircraft flying under existing directives, which includes flights at altitudes not lower than 30,000 ft overland. Here is a summary of that statement:

Sonic boom will not damage the following:

1. Concrete driveways, walks, slab floors, patios, basements, retaining walls, and like items.
2. Concrete, block, or stone construction, brick or stone chimneys, brick or stone veneer, mortar joints, and like items.
3. Directly damage automobile glass, television safety screens, television picture tubes, electronic components of television or radio sets, water closets and commodes, and like items.

In addition to the statement about what a sonic boom can not do, the rear of the claim form acknowledges that a sonic boom may cause glass damage and may aggravate preexisting plaster damage. Each of the statements of damage policy presumes that the damaged items are not at such a state of failure that a sonic boom may trigger or accelerate already impending damage.

In the event that a sonic boom damages glass, the Air Force will pay for the reasonable cost of replacement. Payment for plaster damage, however, is limited to a maximum of 50% of the cost of repair, including painting, based upon Air Force experience that sonic booms will not cause damage to new plaster. Exceptions to this policy will be made for such rare situations as when green, newly-set plaster is damaged as a result of a sonic boom. In such situations it would be obviously unfair to pay less than the full repair cost since all of the damage was the result of the sonic boom.

Table 1 presents a list of claims for sonic boom damage in all types and categories which have been presented to the Air Force since Fiscal year (FY) 1956 and their disposition. Although a precise analysis has not been made of all these claims, many for the years prior to 1960 involved specific accidental

Table 1. Summary of sonic boom claims presented in the United States to the Air Force.

Fiscal Year	*No. of Claims*	*Dollars Claimed*†	*Approved in Whole or Part*	*Dollars Approved*
1956	36	$ 12,000	$ 21	$ 2,000
1957	372	157,000	286	19,000
1958	522	196,000	235	40,000
1959	632	285,000	243	21,000
1960	681	108,000	227	20,000
1961	1,146	703,000	527	57,000
1962	3,092	990,000‡	1,451	132,000
1963	7,200	4,023,000	2,268	239,000
1964	5,102	3,545,000	1,664	183,000
1965	9,574	4,938,000	2,490	256,000
1966	4,856	3,284,000	2,123	211,000
1967	2,216	1,732,000	1,080	145,000
1968*	3,054	2,236,000	1,278	135,000
Total	38,483	$ 22,209,000	$ 13,893	$ 1,460,000

* Ten months only.

‡One claim for $19 million not included.

† Rounded to nearest thousand dollars.

low-level incidents. For example, the claims arising out of the low-level demonstrations at the Oklahoma City Air Show in September 1956 undoubtedly affected the large increase in claims in FY 1957 as compared to FY 1956. Accidental low-level flights at Panama City, Florida; Cedar City, Utah; and in the San Francisco Bay area in 1957 and 1958, also greatly increased the number of sonic boom damage claims for the years prior to 1960. In 1961, the Strategic Air Command began flying the B-58 bomber supersonically over cities in the midwestern United States in order to test its radar bombing mission. The planes flew regularly and often over prescribed routes and the results of the simulated bombing were scored electronically on the ground. The effect on claims was significant as the table shows. In addition, the Federal Aviation Administration in February 1964 commenced 1253 supersonic test flights over Oklahoma City, thus swelling the statistical claims load for FY 1965. The number of claims for FY 1966 was increased by more B-58 flights in calendar year 1965 over Chicago, Milwaukee, Pittsburgh, St. Louis, and Minneapolis. In 1967, the SR-71, a high level reconnaissance aircraft, began supersonically flying on regular routes throughout the United States to test its photographic sensor equipment. Its effects may be seen in the claims statistics for FY 1967 and FY 1968. In particular, the results of the overflights of Chicago, Illinois may prove interesting. Table 2 shows that 51 SR-71 supersonic flights were made over Chicago during the period from July 3, 1967 through October 2, 1967. As of April 17, 1968, these flights had resulted in a total of 391 claims presented to the Air Force, of which 345 had been processed. Of those processed, 95 were approved in the total amount of $6,470 and 239 disapproved, for a ratio of nearly 40% paid. Eleven were withdrawn. During the same period, 2309 damage complaints were received by the Claims Office at Chanute Air Force Base, Illinois. As may be seen, the ratio of claims to complaints, more than one out of five, is slightly lower than the previous experience of approximately one out of three. The City of Chicago had previously been subjected to B-58 sonic booms from January through March 1965, from B-58s on their bomb scoring runs. Table 3 shows an interesting comparison of B-58 and SR-71 flights over Chicago. For a comparable period of time, though with slightly fewer booms, the SR-71 had a much smaller

TABLE 2. SR-71 sonic boom claims and complaints from flights July 3– October 2, 1967.

City	*Total Damage Complaints**	*Total Claims**	*Total Overflights*
Chicago	2,684	315	51
Los Angeles	974	352	20
Dallas/Ft. Worth	256	65	61
Minneapolis/St. Paul	233	52	48
Indianapolis	175	69	50
Denver	162	55	48

* As of January 3, 1968.

TABLE 3. Comparison of B-58 flights and SR-71 flights over Chicago.

Comparison	*B-58*	*SR-71*
Period Covered	Jan 4–Mar 4, 1965 (59 days)	Jul 3–Aug 30, 1967 (58 days)
Number of Booms	34	27
Number of Complaints	3,548	1,100
Number of Claims	507	67

impact upon the citizens of Chicago. Though the reasons for this are not known, the greatly higher altitude and subsequently somewhat less severe boom of the SR-71 may be a primary factor. Even as of April 1968, fewer than 400 SR-71 claims had been received from 51 supersonic flights compared with 3156 claims from 49 B-58 flights.

As was seen in Table 1, roughly one claim out of every three presented to the Air Force has been approved in whole or in part. As might be expected, however, claims-to-payment ratios have varied depending upon the type of aircraft involved, number of sonic booms, nominal overpressure of the sonic boom created, and many other factors.

A recent analysis of sonic boom claims presented to the Air Force reveals some of the variations which may be received. Table 4 shows a comparison of claims received arising out of B-58 flights over four cities in 1965 and all the other claims received by the Air Force during FY 1966. As you can see, the percentage of paid claims runs somewhat higher than has been the overall average since 1956 (see Table 1). It might also be noted that the percentage of other claims to complaints runs somewhat higher than the three-to-one ratio which has been the general experience of the Air Force in the past. Special claims offices were set up in the cities involved and the ease of presenting claims could have been a factor in this result.

Table 4 describes a few of the general damage observations made by analyzing the claims files, and describes the 4901 claims from the Oklahoma City supersonic overflights of January through June 1964. As might be expected, the overall predominant type of damage is glass damage, which represents nearly three-quarters of paid damage incidents in Chicago, Pittsburgh, and for FY 1966. For claimed damage (as opposed to paid damage) glass, plaster, and miscellaneous damage was claimed in almost equal amounts by owners of single family structures. However, glass damage was claimed most prodominantly by owners of commercial structures, involving around 78% of such claims. The average paid claim alleged approximately $93 in damage but the amount paid averaged approximately $72. For all paid claims, including those involved in the Oklahoma City tests, the percentage of damage was 65% glass damage, 21% plaster damage, 8% damage as a result of falling objects, and 6% miscellaneous damage (see Table 5).

Generally speaking, when comparing the percentage of paid claims to denied claims, it was found that about three times as many glass claims were

TABLE 4. Claims comparisons for B-58 flights over four cities in 1965 and all other sonic boom claims received by the Air Force during FY 1966.

				Damage Claims			*Claims Paid*	
Boom Area	*Total Booms*	*Boom Dates*	*Damage Complaints Received*	*Received*	*% of Complaints*	*Claims Adjudicated*	*Paid*	*% of Adjudicated*
Chicago	49	Jan-Mar 1965	7,128	3,156	44	3,116	1,464	47
Pittsburgh	50	April–June 1965	1,848	1,102	60	1,088	503	46
Milwaukee	61	July–September 1965	953	639	67	621	259	42
St. Louis	22	July–September 1965	1,390	491	35	476	215	45
All Other Claims	–	June 1965–June 1966	–	–	–	1,409	721	51

paid as denied. On the other hand, five times as many plaster claims were denied than were paid.

There are other interesting damage facts produced by the study. For example, owners of property will claim sonic boom damage about three times more often than lessees of property. (Naturally, allowance was made for the different ratios of owned property compared to leased property.) It also appears that the claims rate for structures less than 25 years of age are about one and one-half times greater than for older structures. The percentage of claims involving single family structures was roughly the same for paid claims from all areas at approximately 70%. Multifamily units, however, composed only around 10% of the structures involved. Even in Chicago, where the number of apartment units in the city roughly equals the number of single-family residences, only 10% of the damage incidents involved multifamily structures. In addition, even in buildings as tall as 40 stories almost all of the damage involved in the claims under consideration occurred on the ground floor.

The study showed that the number of cases of personal injury and injury to animals was extremely low. There were 0.7 cases of personal injury per 1000 claims in the five city boom areas and 3.5 per 1000 claims on a nationwide basis in FY 1966. For animal injuries the rate was 1.3 per 1000 claims in the cities and 13 per 1000 nationwide in FY 1966. It should be noted that most of the claims for personal injury received by the Air Force have been of an indirect

TABLE 5. Paid sonic boom claims for FY 1966.

Damage	*Percentage of Paid Claims*
Glass	65
Plaster	21
Fallen Objects	8
Miscellaneous	6

nature. In other words, the claims usually involve such incidents as persons struck by falling objects or having been startled into injuring themselves.

Although occasional claims for loss of hearing, nervousness, or shock have been received without accompanying physical contact, these claims have not been favorably considered. It has been the experience of the Air Force that individuals can easily withstand the moderate overpressures involved in sonic booms created by aircraft flying under prescribed directives. In fact, it has been ascertained that even high overpressure sonic booms have been unable to cause damage to human beings. An interesting test was conducted by the Air Force in this regard in June of 1965, at Tonopah, Nevada. A number of supersonic flights by F-4C aircraft at low level were made over people, structures, and animals. The people involved, who ranged from young to middle age and even several elderly persons in reasonably good health, did not sustain any real injury although overpressures of 60 psf were measured nearby. In fairness, it must be stated that the nonmilitary people involved were for the most part pioneer stock who had been warned in advance of the tests and who had previously experienced many sonic booms.

The horses and cattle in the vicinity were likewise unaffected by sonic booms which ranged from 25 psf to over 120 psf on the flight track. The highest recorded measurement was 144 psf. The animals had been exposed to aircraft regularly for months or years. Though startled, most of the cattle began to graze again within a minute or two after experiencing the sonic boom. Horses, likewise, experienced practically no reaction to the booms. Another factor which must be, of course, considered is that these animals were not restricted in any way by fences or enclosures. In other words, since the animals had the freedom to run, their reaction might not be typical of other animals throughout the country.

In order to try to obtain a better understanding of possible effects of sonic booms on animals, I have tabulated all of the animal claims processed since 1962.

Only 192 claims have involved damage to animals out of the total 35,094 claims in all damage categories which have been disposed of by the Air Force between FY 1962 and April 1968. A breakdown of these claims may be seen in Table 6. A high percentage of these animal claims involved an injury resulting from startle and sometimes panic. Often, a claimant alleged that the productivity of female animals was affected by the startling effect of a sonic boom, e.g., loss of poultry production. In other cases, the hatchability of eggs was alleged to have been affected by sonic booms. However, studies have shown the effect of sonic booms on eggs to be minimal. Often the claims are somewhat speculative as to the cause of damage, as when an animal is discovered to have injured itself sometime during a time span when a sonic boom occurred. Other cases are even more speculative as to cause and effect. In one case a dog, allegedly frightened by a sonic boom, ran over a half mile and was struck by a car. The claim was denied.

TABLE 6. All animal claims processed since 1962 by the Air Force.

Category	*No. of Claims*	*Dollars Claimed*	*No. Approved*	*Dollars Paid*
Hogs	1	$ 125.00	1	$ 87.00
Rabbits	4	900.00	1	350.00
Pheasants	3	19,209.00	1	17.00
Turkeys	11	51,705.00	4	18,608.00
Mink	18	205.420.00	12	25,925.00
Eggs	18	7,163.00	1	3.00
Dogs	20	3,821.00	3	146.00
Cattle	23	10,162.00	13	3,569.00
Horses	35	43,943.00	15	5,604.00
Chickens	45	85,018.00	21	6,256.00
Other	14	57,330.00	4	381.00
Total	192	$ 484,796.00	76	$ 60,946.00

In the area of personal injuries, the Air Force has closed 10 claims during the period July 1966 through March 1968. The total amount claimed for these 10 claims is almost $261,000. However, it should be noted that this figure has been considerably enlarged by a single claim in the amount of $200,000, which was disapprovd. Only three of the 10 claims were paid, the total amount paid being $1,850.74. Two of the three paid claims involved individuals cut by glass which had been broken as a result of a sonic boom.

To date, personal injury claims, resulting either directly or indirectly from sonic booms, have been comparatively few and generally of a minor nature. The most dangerous effect, aside from startle, appears to be from falling objects or from broken glass. It was learned in the Tonopah tests that low-level sonic booms will actually cause glass to fly some distance from the broken pane thus creating a serious danger. While such accidental low-level sonic booms are rare, they are not impossible despite constant vigilance. One of the most recent of such low-level incidents occurred on June 9, 1966, at Washington Court House, Ohio, when an F-4 with a faulty mach-speed meter exceeded the speed of sound at an altitude of about 1000 ft without the pilot being aware of it. Over 300 complaints and over 200 claims were received as a result of this single incident.

In conclusion: Some damage from sonic booms has occurred as a result of Air Force activities. Future damage can be reduced to some extent by establishing flight paths which will minimize sonic boom exposure. Altitude restrictions have also undoubtedly reduced the amount of sonic boom damage, but even at the heights of over 70,000 ft flown by the SR-71, some claims have arisen. While the Air Force presently restricts supersonic flight over metropolitan areas to the extent possible consonant with maintaining operational readiness, the growth of dense urban areas throughout the country is making such avoidance increasingly difficult. Hopefully, scientific studies now in progress throughout government and industry, and conferences such as this one, will provide some solutions to help the Air Force to reduce or prevent the future adverse effect of sonic booms.

Acceptable Nominal Sonic Boom Overpressure in SST Operation[1]

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The question of the acceptable intensity of the sonic boom that would be created by the planned civil Supersonic Transports (SST) cannot be adequately dealt with as an isolated problem. It must be judged in relation to the need for and economy of supersonic transportation and any special drawbacks (other than the boom) that it might have.

Clearly, if a noise-creating activity is greatly needed for society, if it does not impose significant hazards and harms, and if it is economically viable, people in general are likely to put up with a somewhat higher noise level than if these conditions are not at hand.

In my full paper a summary is made of my findings about the pros and cons of the SST as expressed in the papers I have written on the subject since 1960.[2] Briefly: I have repeatedly stated and, I think, proven that there is at best a moderate need for the SST, that it will be much less safe than subsonic aviation, and it will be grossly uneconomical, in particular if limited to oversea operation.

Today I am convinced more than ever that the marginal need for the SST is so greatly outweighed by its deficiencies in safety and economy that it would be a grave mistake to launch the enterprise—even if the scourge of the sonic boom did not exist.

This paper is based mainly on coordinated evaluations of sonic boom tests over Oklahoma City in 1964 and at the Edwards Air Force Base in 1966 and 1967.

Supersonic SST Operation Over Land

Hundreds of Millions of "Superbooms"

Sonic boom is produced by two huge conical shock waves that emanate from the front and rear of an aircraft flying at supersonic speed. Besides its startling double-clap signature, the sonic boom differs from all other kinds of noise in two decisive ways: The tremendous vastness of area covered—boom carpets

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[1] Abbreviated version. The full paper, BL Report 110, which contains also a presentation of the case against SST operation over sea, can be obtained from the author.

[2] A selection of my writings is listed in the reference list as well as an SST-opposing statement in the House of Lords in 1962, by the late Lord Brabazon of Tara (1962).

stretch along the whole supersonic path and will be for the SST some 50 to 80 miles wide (see Figure 1); the exceptionally great variation, or scatter, in boom intensity.

The unpredictability of boom strength has been observed ever since military supersonic planes began to fly, but the Oklahoma tests showed that the scatter is much greater than anyone thought before (Hilton et al., 1964; Lundberg, Dressler, and Lagman, 1967). The main reasons for the great variability—and hence the high probability or frequency of great magnifications above the nominal boom intensity—are various atmospheric conditions such as winds, turbulence, and irregularities in temperature distribution, e.g., "inversion waves" (Johnson, 1967a, 1967b). Flight maneuvers, turns, changes of the angle of attack, acceleration, etc., will also cause local magnifications of the boom. Furthermore, crossing of the courses of two SSTs (which cannot be avoided with dense SST traffic) will result in doubling of the boom along a narrow intersection zone (Lundberg, 1961b).

Figure 2 illustrates some implications of boom scatter. A typical SST boom carpet is shown for supersonic climb and initial cruise. The heavy-drawn curve, marked by the "probability level" ½, in section A-A across the carpet indicates a nominal peak overpressure, △ P, on the flight track of 2 psf. This is roughly the nominal boom intensity of current SST projects at initial cruise at 55,000–65,000 ft; it falls off to about 1 psf at the carpet edges. The nominal peak △ P will taper off to about 1.75 psf at end of cruise due to reduced aircraft weight and increased altitude as fuel is burnt.

The nominal boom will be at least 25% greater at start of supersonic climb that initial cruise—thus about 2.5 psf—because transition to supersonic speed takes place at lower altitude, 30,000—40,000 ft.

Moreover, in the first portion of the climb carpet the boom will be magnified by a factor of 2–2.5 within a horseshoe-shaped area. (Newberry, 1964; Maglieri, 1965; Sawyer, 1955). The reason for this is focusing on the earth of the shock-wave rays soon after acceleration through the speed of sound. The arms of the horseshoe, extending some 10 to 15 mi from the track, are relatively thin, probably about 300 ft. It has therefore been difficult to "catch" these magnifications in tests, but it has been done. In real operation the horseshoe, with its potentially destructive booms up to some 6 psf, will inevitably "cut through" built-up areas if supersonic flights take place over land.

Each of the curves denoted by the "probability levels" $^1/_{10}$, $^1/_{100}$, etc., in section A-A indicates the probability of any point in a cross-section of the carpet being subjected to a boom stronger than the magnitude indicated by the curve. These probability/magnification curves are derived from the Oklahoma test (Lundberg et al., 1967). They must not be confused with pressure distribution curves for a particular flight. To make this clear, the dotted curve illustrates a conveivable pressure distribution for an overflight that happened to produce over 4 psf in point P.

To understand the effects of the boom it must be recognized that the boom usually hits every point within the whole carpet. One must, of course, consider

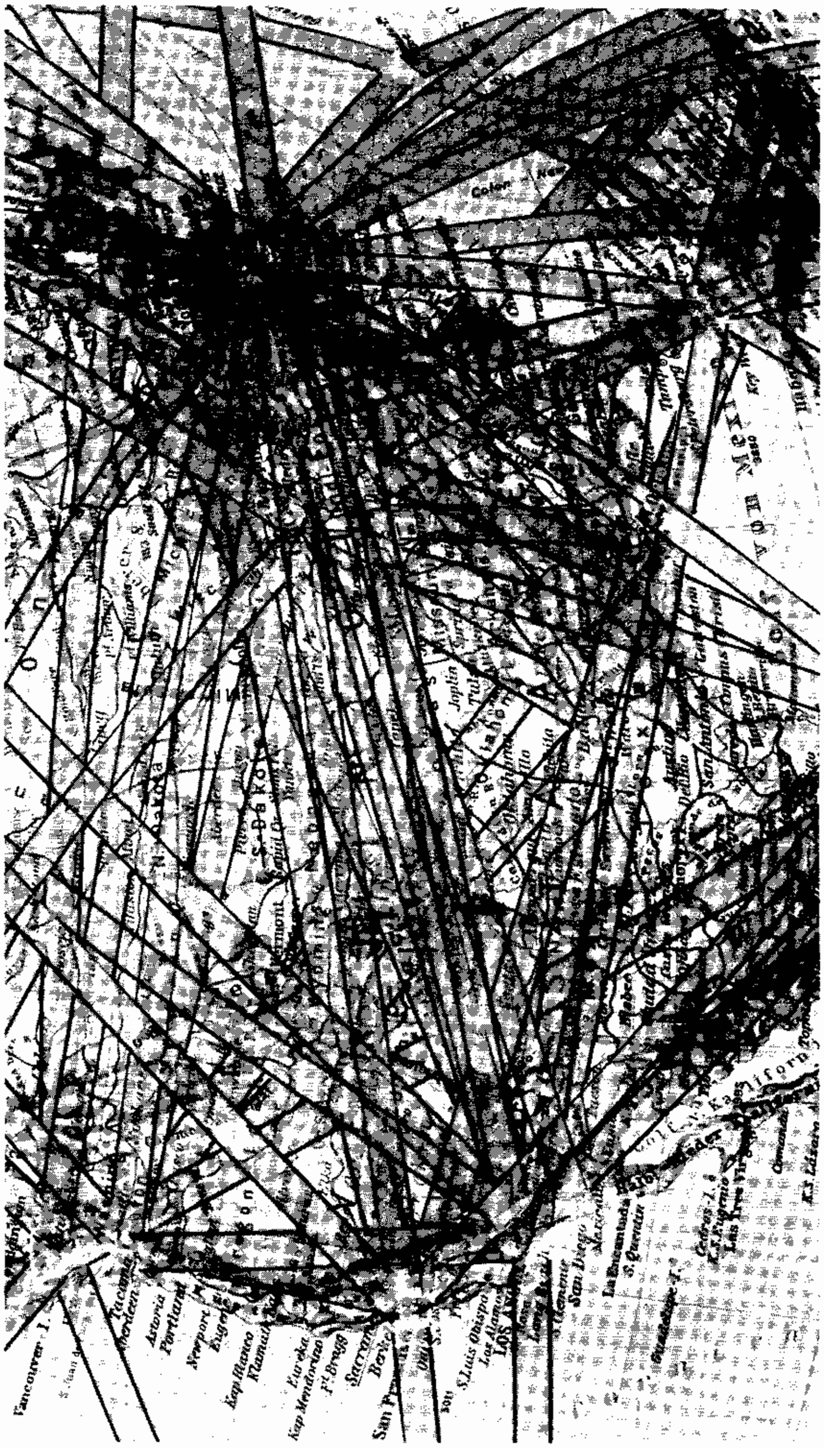

FIGURE 1. Sonic-boom carpets over North America.

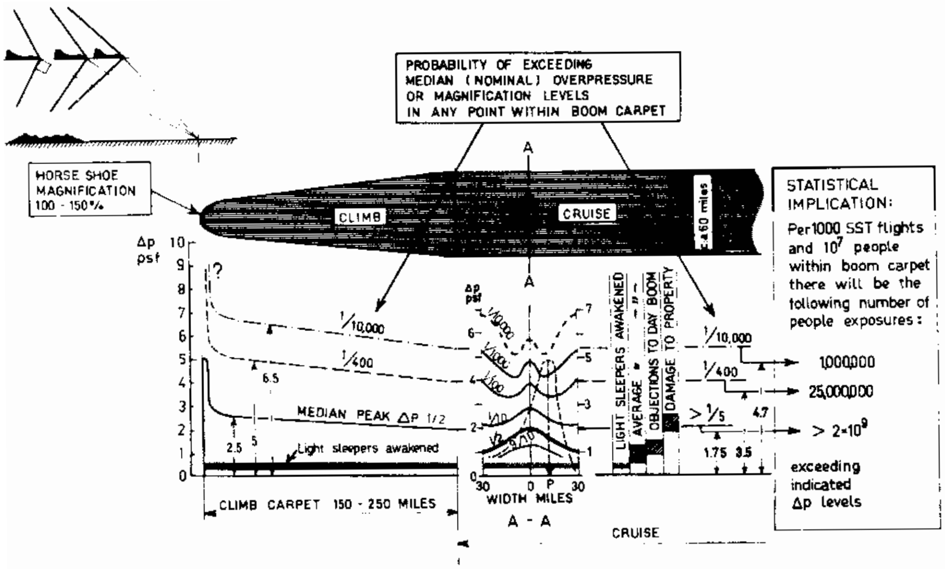

FIGURE 2. Distribution of nominal boom overpressure and the exceptionally great scatter—hence great magnifications—in overpressure (Δ P). The statistical implicaion is that the boom usually hits every spot within the carpet and thus every boom-sensitive object (humans, animals, fragile portions of structures).

only those points or objects that are detrimentally affected either by one single boom or by cumulative effects of repeated booms. But the boom-sensitive objects within the carpet—humans, animals, fragile portions of structures, etc.—are indeed numerous. For typical SST flights, such as New York–Los Angeles or London–Athens, there will normally be 10 to 20 million people within the carpet. The number of animals and boom sensitive spots in structures might be of a similar order of magnitude.

It is convenient to consider the number of exposed people together with the number of exposures (i.e., overflights) by defining a "unit number" of "people exposures," e.g., 10^{10}. This might correspond to 10 million people and 1000 SST flights (about 3 flights per day in one year) or 1 million people subjected to 10,000 overflights. Multiplication of the "unit number" by a particular probability level yields the number of people exposures to booms exceeding the corresponding probability/magnification curve.

Thus there will be 5×10^9 people exposures to booms exceeding the median boom intensity. If we, conservatively, take the median peak overpressure of about 1.75 psf at the end of cruise as a basis and apply the average probability (between $^{1}/_{10}$ and ⅕) of exceeding this level, the unit number yields 2 billion people exposures to booms over 1.75 psf.

For probabilities below 50% the scatter increases toward the carpet edges. As follows from section A-A, Figure 2, the risk of "superbooms"—the common name for booms over 3 psf—is, in fact, even greater on the outskirts of the carpet than in its central region. Thus, the magnification factor over the median intensity on the flight track will usually exceed, on average, 2 for every 400th and exceed 2.7 for every 10,000th overflight in every point. Multiplication by 10^{10} and application again of the reduced median peak intensity of 1.75 psf at end of cruise yields, for the unit number 25 million superbooms exceeding 3.5 psf and 1 million terrific superbooms exceeding 4.7 psf.

Then, how many "people exposures" to superbooms will there be all over the world? Let us assume that the "unit number" is, on average, obtained by 1000 SST flights per year on a typical route of 2000 mi. Assuming an average of 150 passengers per SST flight this would amount to 30×10^7 passenger miles. If there are no boom restrictions FAA estimates the potential demand (air traffic over 700 miles) for SSTs to be over 1200×10^9 passenger miles yearly by 1990 and that more than half of this market would be flown by SSTs (Institute for Defense Analysis, 1966). If this optimistic estimate is reduced by a factor of 3 (corresponding to a market of about 450 SSTs) and if it is assumed that half of the operation is over sea there will still be some 100×10^9 supersonic passenger miles over land, i.e. about 300 times more than the traffic volume corresponding to the unit number.

Thus the worldwide number of people exposures to booms would be on the order of 600 billion exceeding 1.75 psf, 7 billion exceeding 3.5 psf, and 300 million terrific superbooms over 4.7 psf.

It will probably be argued that the current, or some future, SST projects might not produce a nominal initial cruise boom on the track stronger than, say, 1.5 psf, rather than the 2.0 psf assumed above. In the first place this seems very unlikely unless the SSTs are made unfeasibly small. Secondly, the list above is conservative because the horseshoe superbooms and the higher nominal boom intensity in the vast climb carpets are not taken into account. Thirdly, the SST booms will most likely display much greater magnifications than assumed in Figure 2.

Discussion of Uncertainties

Calculations of the frequency of superbooms can never be exact, even if one knew accurately the SST traffic volume and the numbers of people within the carpets. One uncertainty is the detailed shape of the boom signature. Further uncertainties are the representativeness, for worldwide atmospheric conditions, of the scatter in overpressure in the Oklahoma tests and the effect on scatter of the higher flight altitudes of the SSTs.

It is not possible to deal thoroughly with all these factors in this paper, but neither is it necessary. The all-important question is whether or not Figure 2 gives the right order of magnitude of the frequency of magnified booms. For this the following observations seem sufficient:

An appreciable proportion of the magnified booms in the Oklahoma tests had a rather peaked signature (indicated by the dotted curve in part A of Figure 3). Booms of this type are less powerful with regard to physical effects on structures and on the bodies of humans and animals. As the magnification curves in Figure 2 apply for △P, they exaggerate the boom magnifications with respect to physical effects. It has been suggested that for such effects impulse, which is proportional to the area within the △ P/time plot, would be a better measure of boom strength. On this basis one could apply the scatter in impulse on overpressure, implying neglect of the cases of very peaked overpressure signatures. As the scatter in impulse in the Oklahoma tests was about ⅔ of the scatter in overpressure there would still be over 300 million people exposures to "full-impulse" booms exceeding (⅔ × 4.7 =) 3.15 psf all over the world, every year, for the supersonic activity assumed above.

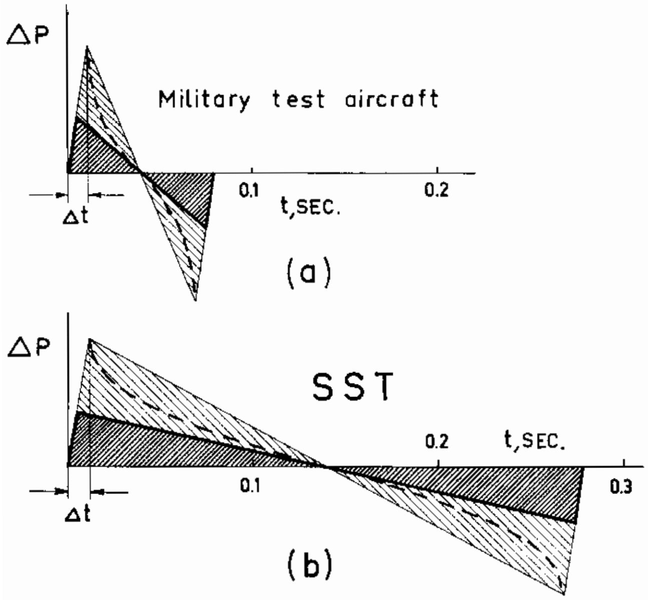

FIGURE 3. Schematic illustration of the N-wave signature of the sonic boom. The duration of the boom is roughly proportional to the length of the aircraft and therefore three to four times greater for current SST projects than for the aircraft used in boom tests. The impulse of the boom is proportional to the area covered by the N-wave (shaded areas) and the energy content to the product of duration and the square of △ P.

But the impulse is not a representative measure of the boom severity except in special cases. As pointed out in Lundberg et al. (1967) the total energy of the shock wave is probably more significant for the physical damage potential. Since total energy is proportional to the square of impulse (at a given duration, t), the energy magnification factors are accordingly greater. They are, in fact, even somewhat greater than the overpressure magnification factors.

According to information received by I. Holmstroem of the Meteorological Institute, Stockholm University, there is no reason to believe that the average atmospheric conditions all over the world are less "boom scatter producing" than were the conditions that prevailed around Oklahoma City during the tests. Many vast districts, such as coastal and mountainous areas, are probably more critical with respect to boom magnification—because of strong wind shear, severe turbulence, irregularities in the vertical temperature distribution, and inversion waves—than the typical continental climate of Oklahoma.

Finally, according to the tests, the scatter in overpressure increased quite appreciably with flight altitude. This is shown in Figure 4. The rough extrapolations made to SST cruise altitude indicate the great magnifications of the SST booms that might be expected. This is not surprising since it is the

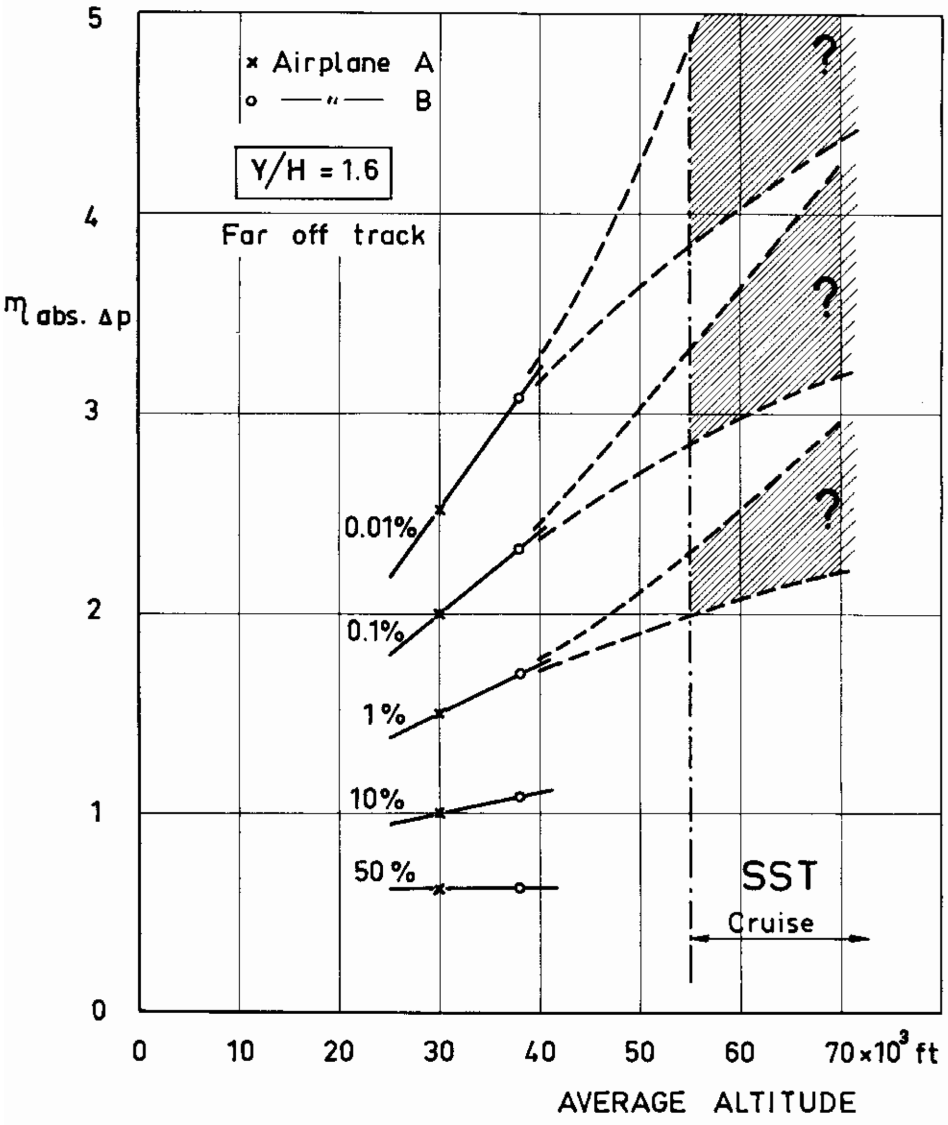

FIGURE 4. Example of increase of Δ P magnification, far-off track, with altitude.

cumulative effect of atmospheric perturbations in the paths of the shock wave that creates the scatter.

Thus the overall picture of boom magnifications that is given by Figure 2 appears to be quite conservative for application on the SSTs, with regard to such physiological effects that are dependent upon overpressure, e.g., loudness, and such physical effects than depend mainly upon the energy content of the boom.

Detrimental Effects of Average and Magnified Booms: Acceptability Criteria

In figure 2 a scale is marked for four boom acceptability criteria: objections to daybooms, awakening of average sleepers, awakening of light sleepers, and damage to property. Each shaded area indicates a conservatively estimated region for the limit at which the effect in question begins to be appreciable.

Some results of the Gallup polls, the main object of the Oklahoma tests, are presented in Figure 5. The objections to daybooms were appreciable at about 0.8 psf and very widespread at 1.4 psf.

In spite of the fact that no boom tests were made at night, some conclusions can be drawn about the effect of booms on "average sleepers." At the end of the tests 18% of Oklahomans polled reported sleep interruptions by an average boom intensity of 1.43 psf, indicating that most daytime sleepers were awakened. After the first phase of the tests during which the average intensity was only 1.0 psf, 14% were awakened, and at this intensity the first boom, at 7 a.m., was widely used as an alarm clock!

Furthermore, in this first poll, the number of those who answered "yes" to the question whether they could "learn to live" with several night booms (of about 1.0 psf) was 22% less than the number who thought they could accept daybooms of this magnitude. Unfortunately, the question was not repeated during the later polls, after the boom intensity had been stepped up. Nevertheless, all the information reported supports the heavy-dotted curve for night boom acceptability marked in Figure 5. The curve indicates that sleep disturbance for average sleepers will be rather common at about 0.5 psf and that probably most people will be awakened by roughly 1.3 psf.

The average sleepers—most of whom are middle-aged or young people in good health—are, however, not significant with respect to boom acceptability. Because of the vastness of the boom carpets it will be practically impossible to escape the boom. This means that the boom will strike all groups of people within the carpets, including sick, nervous, and elderly people, and insomniacs, as well as people who are "light sleepers" but otherwise may be in good health.

If the sonic booms are not acceptable to such people, they are not acceptable at all in any country adhering to basic humanitarian principles. Surely, it is this "critical group" that is decisive for the interpretation of the following clause in the resolution by (the International Civil Aviation Organization (ICAO,

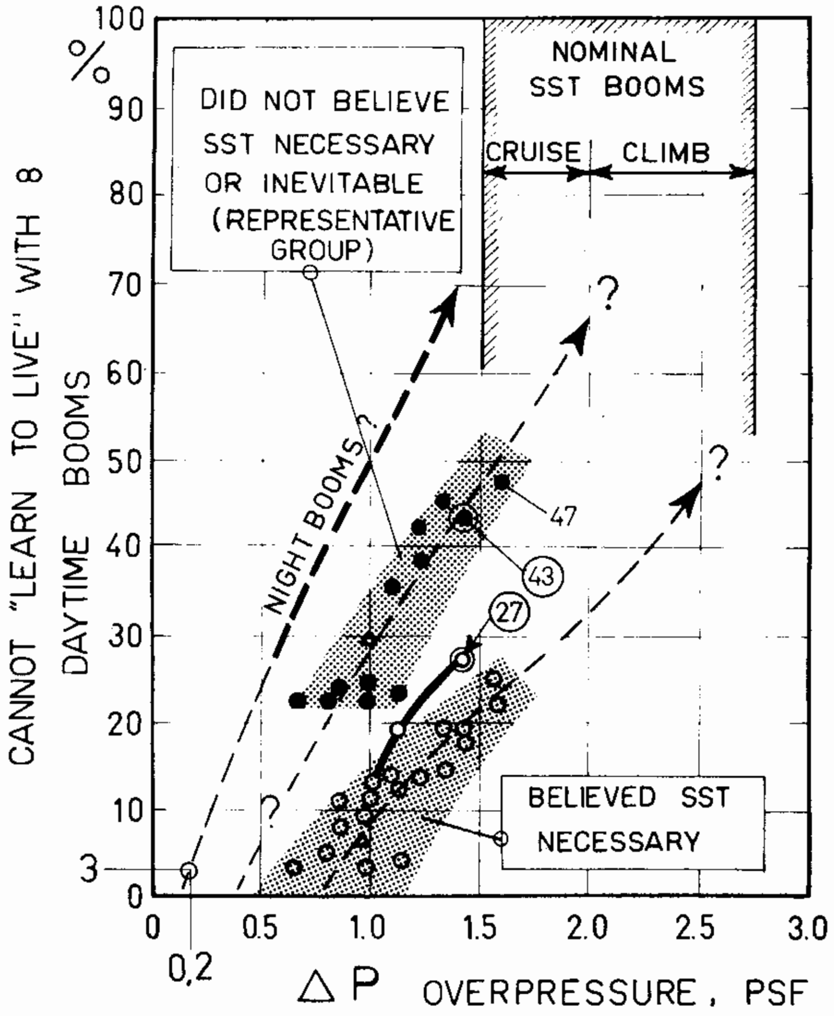

FIGURE 5. Community reactions in Oklahoma City to sonic booms. The overall reaction to 8 daytime booms of residents living within the whole boom carpet is indicated by the heavy full-drawn curve. The other circles and the black dots show the opinion of the two indicated main groups as obtained from the polls for different portions of the boom carpet. The estimated acceptance of night booms of about 1.0 psf was 22% less than for day-booms. Application of this difference in acceptance to the curve for the "representative group" together with information about sleep interruption due to "day booms" supports the heavy-dotted curve marked "night booms."

1962a): "SSTs must be able to operate without creating unacceptable situations due to the sonic boom."

For the definition of the *critical group* it seems practical to attach particular significance to one important portion of the group: the light sleepers. They are probably the least ambiguous portion of the critical group and they lend themselves more easily to boom disturbance tests, such as sleep interruption tests, than do sick and nervous people.

The definition of light sleepers could be based on normal sleep-interruption tests with groups of people representative of the whole public. Such tests yield curves of the percentage of people awakened versus the level of stepwise increased noise stimuli, preferably sudden ones resembling the boom. The light sleepers are naturally defined as x percent, say 20%, that are awakened, counted from the lower end of the sleep-interruption curve.

The next question is which percentage y of the light sleepers may justifiably be awakened by booms of the intensity that can be deemed acceptable. Many people belonging to the critical group may understandably feel that this percentage should be almost zero. This would exaggerate the case, because moderate noises occur evenn in quiet environments; however, y must be fairly small to attain a reasonable protection for the critical group.

In my opinion it would be a cruelty to the suffering people who comprise the critical group, to let more than 10%–20% of light sleepers exposed to booms to be awakened. A higher proportion could hardly be defended even if one assumes that the SSTs are greatly needed. Thus the product $x \times y$, the portion of the whole public that would be awakened by booms of acceptable intensity, would be about 3%.

In 1961, when I first dealt quantitatively with acceptable boom intensity and sleep disturbance (and advocated night boom tests and sleep interruption research as being critical for the feasibility of the SST), I estimated the limit to fall between 0.15 and 0.25 psf (Lundberg, 1961b). This estimate is confirmed rather than contradicted by the Oklahoma tests: If the heavy-dotted curve in Figure 5 is extrapolated downwards, it might well pass the point 3% and 0.2 psf. In Figure 2 the boom acceptability limit for light sleepers is conservatively assumed to fall between 0.25 and 0.5 psf.

This region is greatly exceeded, throughout the length and breadth of the carpet, by the nominal SST boom. Thus most light sleepers will be awakened by practically every SST overflight and a great many sick, nervous, and elderly people would suffer badly, day and night. Many sick people suffer also from sleeping difficulties and for them recovery might be critically dependent upon undisturbed sleep.

These conclusions apply for the theoretical case of no boom magnifications. Obviously, it must be taken into account that the nominal intensity on the flight track is very often greatly exceeded. Then, to which level must the nominal peak boom be still further reduced to prevent light sleepers from being awakened too often by magnified booms? Clearly, a safety factor should be applied as advocated in 1961 (Lundberg, 1961b). The exact magnitude of the factor depends upon whether or not one regards the SST as greatly needed, safe, and economic—briefly, whether one is for or against the SST.

Even for the first case it does not seem justifiable to let a light sleeper be awakened more often than every 10th or 20th overflight. It follows from Figures 2 and 4 that this corresponds to a magnification factor of close to 1.5.

If one does not agree that SSTs are needed, and equally safe and comfortable as subsonic aircraft, the acceptable limit should reasonably account at least for magnifications occurring with an average frequency of roughly 1/1000 considering that there will be many areas affected by 100 or more SST overflights daily. Figures 2 and 4 show that the corresponding safety factor should be about 2.5.

To be definitely on the conservative side these safety factors might be applied on the initial nominal cruise boom in spite of the fact that great numbers of people live in the vast climb boom carpets with their higher nominal boom and horseshoe superbooms.

On the above assumption that the light sleeper's limit lies between 0.25 and 0.5 psf, division by the factors 1.5 and 2.5 yields the following approximate upper limits for the nominal boom on the track: those for SSTs, 0.2-0.3 psf, and those against SSTs, 0.1-0.2 psf.

Booms of an average intensity conforming with these criteria would be much too weak, even when greatly magnified, to cause noticeable damage to property. In view of this there is little need to deal with these boom criteria, because the question of the acceptable boom intensity must, of course, be determined solely by the most critical of the various conceivable criteria: the one required to protect those people who will suffer from the booms.

There has, however, been so much research, testing, speculations, and irrelevant conclusions about structural boom damage that a few words might be said about it.

It has been abundantly confirmed that the lower limit for structural damage is about 2.0 psf for one-time application and, consequently, less for repeated booms. The number of cases of superbooms that will strike fragile portions of structures would undoubtedly run into tens of millions per year all over the world. Statistical evaluations of paid-out compensations for structural damage due to various boom tests indicate that extensive SST operation over the U.S. would result in boom damage payments on the order of \$1-\$3 million dollars per day (Citizens League Against the Sonic Boom, 1968). According to another estimate (from an SST-favorable U.S. report) the damage would amount to \$50-\$100 million dollars per year.

These estimates may well indicate the probable order of magnitude of SST boom damage. But even if the damage would only cost $^1/_{10}$ or $^1/_{1000}$ of the figures quoted, supersonic overland operation would be entirely unacceptable. The mere possibility of "civil" booms causing damage to official buildings, private homes, or fragile portions of historical buildings, (e.g., priceless stained glass in old churches) must, of course, be prevented by law. This the ICAO has supported by its statement of 1962b: "The [boom] intensity must obviously not be great enough to cause any damage to property."

Thus to try to find out in detail by further boom tests the extent of structural damage that would be caused by worldwide SST operation seems pointless and even harmful. Continued preoccupation with structural boom damage might lull people into the false belief that if the boom does not cause extensive damage this would prove that the boom is acceptable.

SST Booms Worse than Close-by Airport Noise

An important part of the recent sonic boom tests at Edwards AFB (Stanford Research Institute, 1967) were the "paired-comparison judgments." Test subjects were subjected to a series of pairs of sonic booms, measured in psf, and fly-over engine noise of a subsonic jet, measured in PNdB (perceived noise decibel). The subjects were asked to judge which sound of each pair was more (or less) acceptable when heard indoors and outdoors. About one minute before the first sound of each pair the subjects were told that a sound would soon occur. This pre-warning implied a greater reduction of the startling effect of the sudden boom than that of the gradually increasing subsonic fly-over noise.

The PNdB level of the noise from the subsonic jet at which 50% of the subjects rated this noise equal in acceptability to a sonic boom with a certain overpressure was determined in the way described by Figure 6. Because of the importance that should be attached to the minority that is more sensitive to sonic booms, I have also determined the intensity of the fly-over noise at which 20% of the subjects judged the boom worse.

The advantage of these kinds of tests is that the sonic boom is compared with a well-known noise to which public reactions have been rather well established.

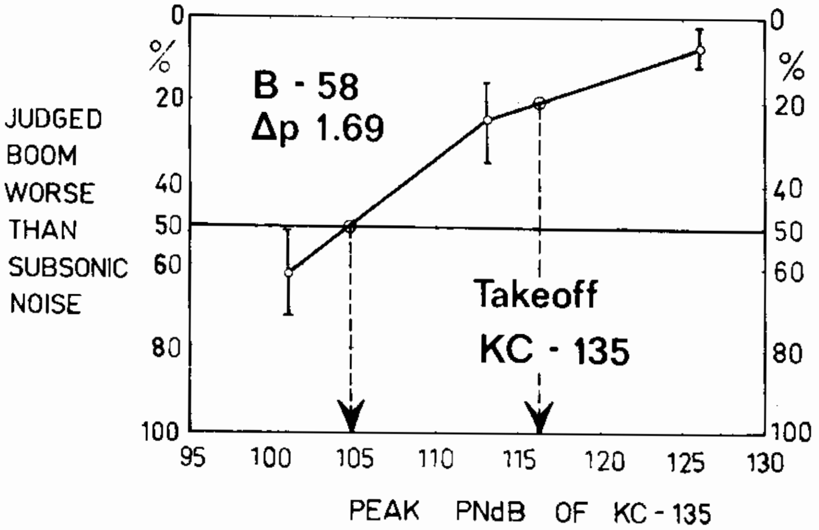

FIGURE 6. Example of results of paired comparison made at Edwards AFB, outdoor listening. The vertical bars mark the 90% confidence limits of data points. The curve connecting the plotted average values on the bars indicates that a boom of 1.69 psf would be judged by 50% of the listeners as worse than subsonic flyover noise of 105 PNdB and by 20% as worse than 116 PNdB.

Figures 7 and 8 summarize the results. The tests with subjects from the residential area of Edwards AFB comprised a fairly wide range of boom overpressure. Instead of the linear scale used in the test report I have used a semi-log scale. Then the data points fit straight-line relationships quite well, making it possible to extrapolate the curves much beyond the range of the tests.

The subjects from Edwards had been subjected to four to eight military booms per day for three years. Thus they were somewhat accustomed to booms and they had probably also a more tolerant or positive attitude to supersonic flight. The subjects from the more quiet civil communities of Fontana and Redland are undoubtedly more representative with regard to boom sensitivity all over the world than are the citizens of Edwards.

For outdoor exposure the boom was only slightly less acceptable to 50% of the subjects from Fontana and Redland than to the subjects from Edwards; the difference for the 20% is negligible. The difference is more pronounced, about 8 PNdB, for indoor listening. Unfortunately, the tests with the subjects from Fontana and Redland were only made with one boom intensity (1.7 psf) but it seems reasonable to assume a parallel with the curves for the subjects from Edwards (as is done in the test report).

Figure 9 compares the four curves for the Fontana and Redland subjects. Up to booms of about 4 psf the indoor curves fall much above the outdoor curves and the slope of the indoor curves is considerably less than that of the outdoor curves. This means that, for one and the same boom overpressure (measured outdoors), the boom, in terms of equivalent flyover jet noise, is much more disturbing indoors than outdoors. The reason for this is that the major energy in a boom is at lower frequencies where the attenuation by the house walls is less than for normal aircraft noise.. At a boom overpressure of 0.7 psf the difference is no less than 15 and 20 PNdB for the 50% and 20% cases, respectively.

Because of the enormous vastness of the boom carpets it is obviously imperative to compare the boom disturbance, expressed in terms of "equivalent PNdB," with the noise levels that are commonly deemed acceptable maxima in environments, or areas, where quiet is necessary. For outdoor exposure such a comparison, as well as comparisons with airport and highway noise, are made in Figure 10.

The two lower curves are the same as those in Figure 7 for Fontana and Redland. As is seen, 50% of people exposed will judge average SST booms (in the middle of the carpet) as being worse than airport noise of 110 PNdB and 20% will find the booms worse than about 120 PNdB. Noise levels exceeding 110 PNdB invariably cause people to complain vigorously.

The upper curve, marked 20%, m=2, corresponds to a magnification of the nominal boom by a factor of 2. Such booms will equal the unbearable severity of 120 to 140 PNdB. Figure 10 shows even higher magnifications will be quite common.

The quantitative degree of the unacceptability of SST booms cannot,

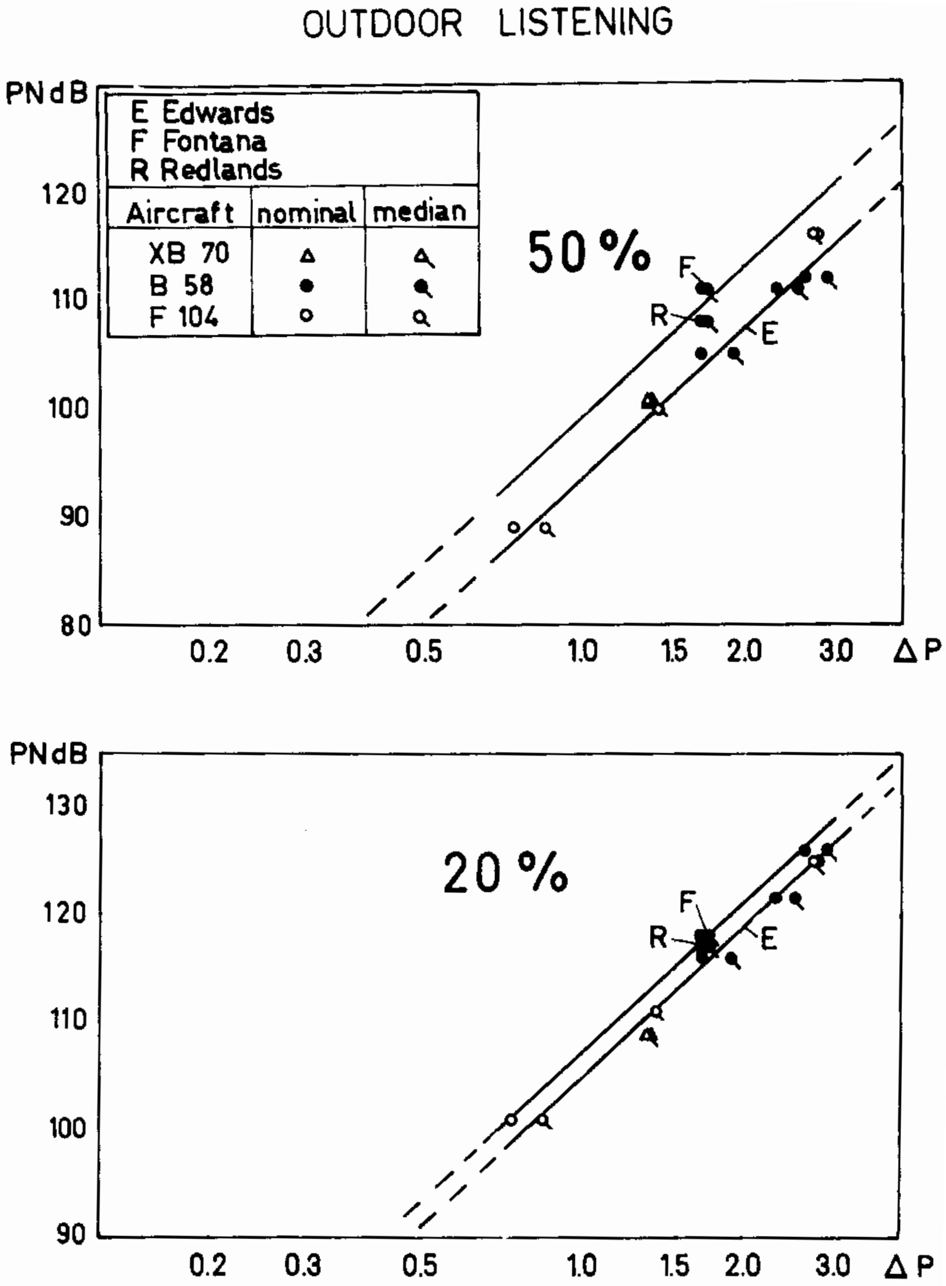

FIGURE 7. Results of paired-comparison judgments for subjects from different communities, outdoor listening. The curves in the upper figure indicate the noise and boom intensities at which 50% judged the boom worse than flyover noise and the lower figure the intensities at which 20% judged the boom worse.

however, be judged merely by comparison with airport noise which is of a local nature. The SST boom carpet is incomparably greater, as is illustrated by the take-off noise carpets (for 110 and 100 PNdB, 4-engined jets) which are hardly visible in the same scale as that of a typical boom carpet. The latter will

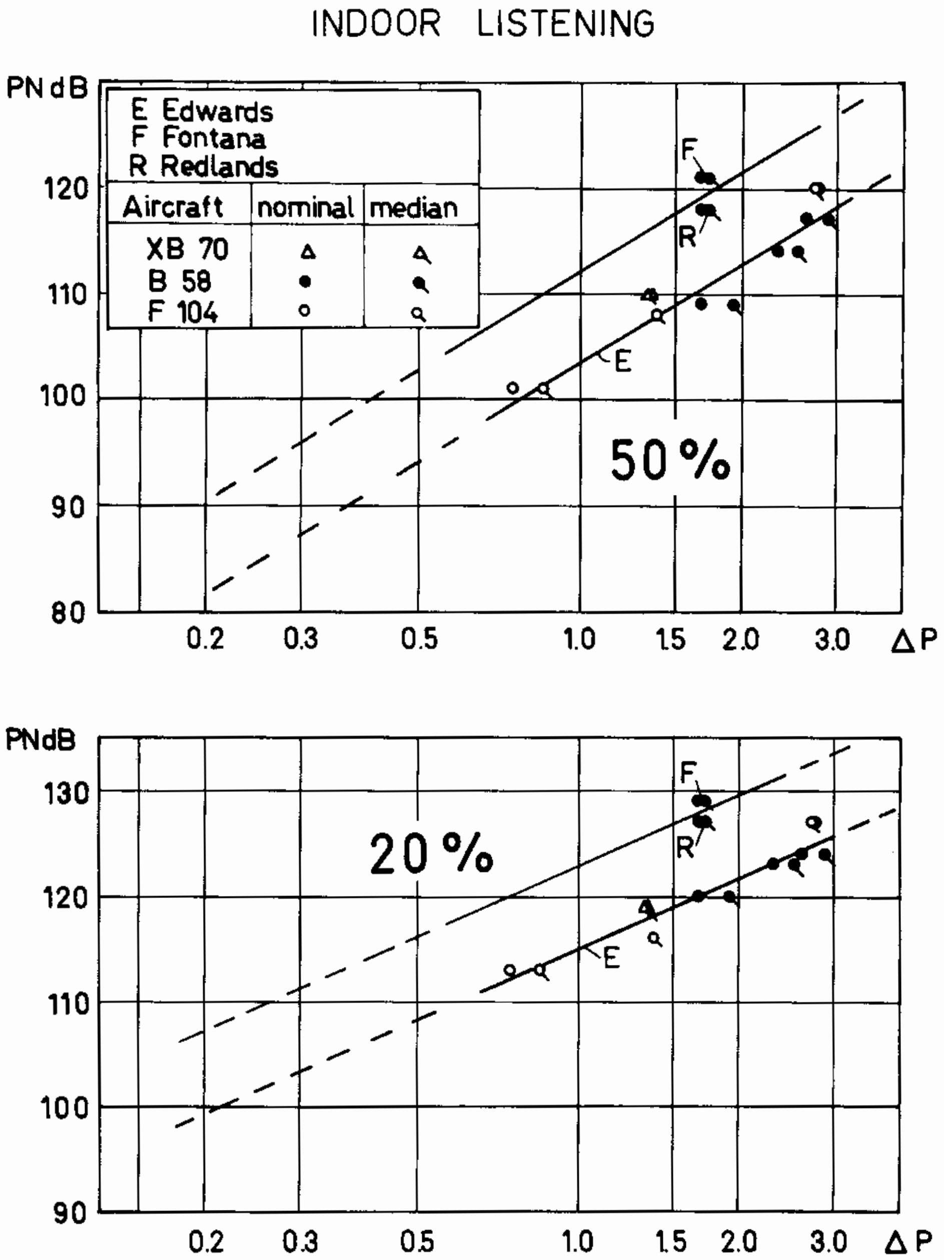

FIGURE 8. Plots corresponding to those of Figure 7, but for indoor listening. The data points refer to PNdB and △ P levels measured outdoors.

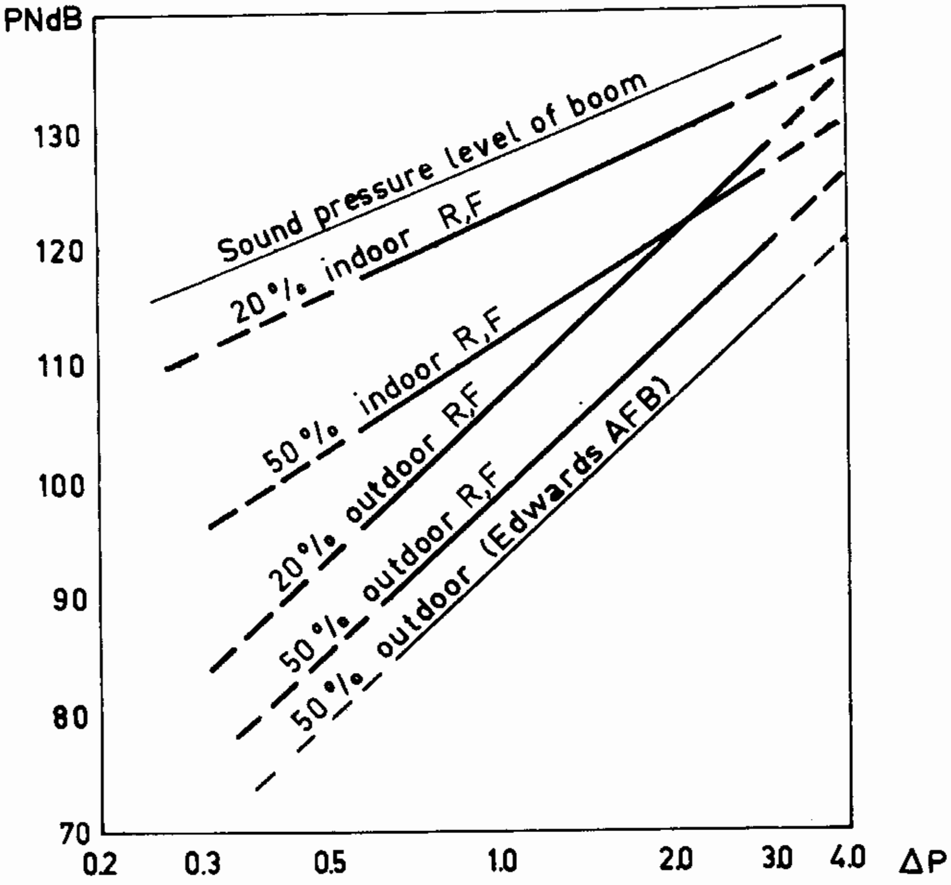

FIGURE 9. Comparison of the paired-comparison judgments according to the upper curves in Figures 7 and 8 for the communities of Fontana and Redland.

inevitably cover not only numerous residential districts but also many recreational areas. Consequently, the boom disturbance, expressed in equivalent PNdB, cannot be allowed to exceed the maximum limits for noise peaks (short-duration noise events) commonly applied or recommended for resorts, hospitals, convalescent homes, or the like.

Scales for approximate limits for significant types of outdoor noise are marked in Figure 10 on the basis of (a) proposals for standards which apparently will soon be adopted by the International Organization for Standardization (1967), and (b) some more detailed standards adopted in Switzerland (Schenker, 1967).

On this basis the limit for frequent noise peaks in recreational areas is about 60 PNdB at night and 65 PNdB in daytime, and it is increased to 70 PNdB for infrequent noise peaks, day or night. As is strikingly illustrated by the figure

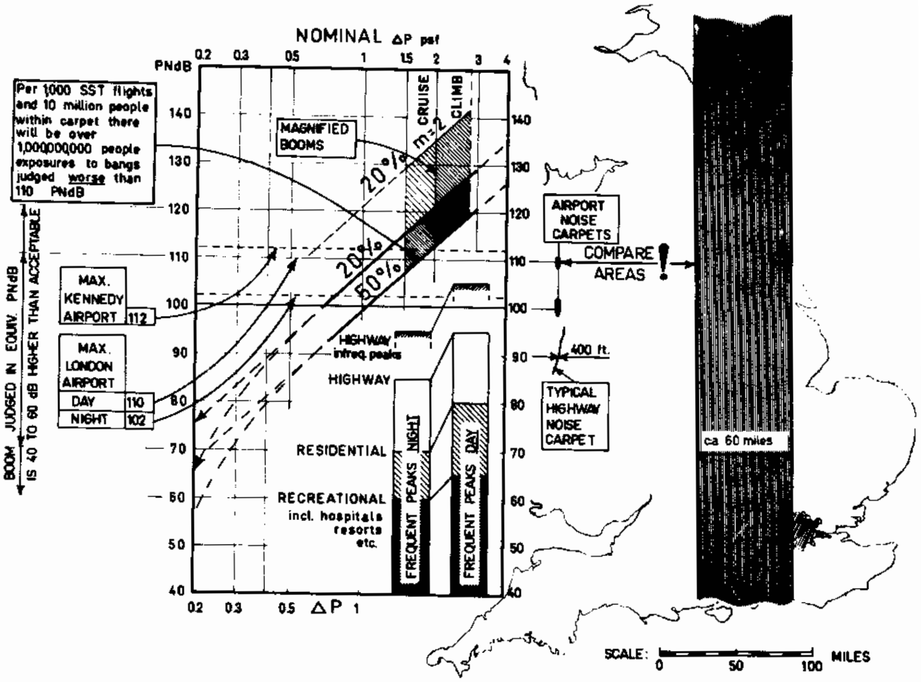

FIGURE 10. Comparison of severity of boom disturbance outdoors in terms of equivalent flyover noise by subsonic jets expressed in PNdB, with (1) the maximum permissible aircraft noise close to the international airports of New York and London, and (2) the levels of frequent noise peaks that are normally deemed or recommended as acceptable maxima outdoors in recreational and residential districts and in built-up areas near highways. The two lower curves, marked 20% and 50%, are the same as the upper curves in Figure 7 (for Fontana and Redland). They are, by and large, representative of nominal booms. The upper curve, marked 20%, m = 2, corresponds to magnification of the nominal boom by a factor of 2. It is obtained by horizontal displacement to the left of the "unmagnified" 20% curve by a factor of 2.

there is a tremendous discrepancy, on the order of 40-60 PNdB, between the equivalent PNdB produced by unmagnified SST booms and the acceptable maxima for recreational areas.

The real prospects are, of course, still worse because of the inevitable magnified booms. The fact that supersonic overland operation by SSTs would, sooner or later, result in superbangs from 3 to 5 psf, or more, striking every recreational and residential area within the carpet, is appalling.

These observations were for outdoor conditions. The disturbing—or rather, shocking—effect indoors of average and magnified SST booms in recreational and residential areas will be even worse (Figure 9).

The paired-comparison approach lends itself quite well for estimation of the acceptable intensities of SST booms. Considering first day-to-day occurrences of boom intensities close to the nominal level, straight-line extrapolation of the two heavy-drawn curves in Figure 10, for outdoor disturbance, down to noise levels of 60 to 65 PNdB, reveal that the nominal boom must not be higher than 0.1-0.2 psf.

Regarding indoor exposure, it should first be observed that even quite weak booms are equally as disturbing as airport noise levels that are usually considered quite annoying. Conservative extrapolation of the 20% line in Figure 9 (assuming the downward-bent circle-dotted curve) indicates that a boom of no more than 0.2 psf would, for some 20% of people exposed, be as disturbing as a jet engine noise of 102 PNdB, the highest permissible noise level at night in built-up areas around London airport.

Then what boom intensity would be acceptable in recreational areas with respect to indoor effects? This is obviously difficult to assess because extrapolation down to the 60 to 70 PNdB levels would have to be more extended than for the outdoor case, in particular for magnified booms. All that can be said with certainty is that the acceptable overpressure level (measured outdoors) with respect to indoor effects is much less than for outdoor effects, implying that the indoor case is the critical or decisive one. A closer study of Figure 9 indicates that the ratio will be at least around 2 and probably on the order of 5 or 10.

If we, conservatively, apply the factor 2, the acceptable nominal boom level will be reduced to 0.05 to 0.1 psf. In view of the imperative importance of preserving high demands on peace and quiet in recreational areas of all kinds it is hard to see that the nominal SST boom can be allowed to exceed the higher of these levels, even if the SST is considered extremely important. Let us, however, assume that the SST enthusiast could defend a nominal level of 0.15 psf. Those who consider the SST unwanted and uneconomic would rightly put the acceptable nominal boom close to 0.05 psf.

By and large this range of limits confirms very well the result of the previous statistical approach applied on the light-sleepers criterion, although the paired-comparison approach yields somewhat lower limits. At the same time it must be considered the more accurate method on the basis of existing test results.

Conclusions

1. Supersonic overland operation of the SST would impose, all over the world, a worse than airport-like environment over numerous recreational and residential areas. To permit this would be an unthinkable atrocity.

2. For the SST boom to be acceptable over land, its nominal intensity must be reduced from the currently anticipated level of about 2.0 psf at initial cruise to the order of 0.2 psf if the SST is believed to be greatly needed and economic and to about 0.1 psf, or even less, if SST operation will be generally regarded as unwanted and uneconomic, i.e., must be subsidized to be kept alive.

3. The question of whether the acceptable nominal boom could be allowed to amount to about 0.2 psf or whether it has to be reduced to 0.1 psf or less, is however, of purely academic interest: At the present and foreseeable state of the art, a reduction of the initial cruise boom below the 2 psf level anticipated for the SST by merely 25% cannot be achieved without prohibitive increase in

operating costs plus drastic reductions in payload and range (Whitlow, 1968). Reduction of 0.5 psf would permit no payload at all.

SST Operation on Oversea Routes

In the full paper (see note to the Introduction) I have also dealt with the case against SST operation with supersonic speed limited to oversea portions of the routes. It is shown that such operation—apart from being grossly uneconomical and offering rather small time-saving for the passengers—will be deemed unacceptable to people at sea because of the sonic boom. From the above analysis, it follows that the nominal cruise boom anticipated for the current SST projects is at least 10 times too severe to be acceptable. The corresponding discrepancy factor for oversea operation is at least three, even if one assumes SST to be greatly needed and economical. Those who doubt this are likely to demand that the nominal SST boom be reduced by a factor of at least five to be acceptable to people at sea.

Bibliography

Citizens League Against the Sonic Boom. Sonic boom damage. Fact-Sheet 11b. February (1968).

Hilton, D., Huckel, V., Steiner, R., and Maglieri, D., Sonic boom exposures during FAA community-response studies over a 6-month period in the Oklahoma City area. NASA TN D25 39, December 1964.

ICAO Assembly. Resolution about the SST. Adopted at the 14th Session, Rome, August 21-September 15, 1962. *ICAO Bulletin*, No. 10, (1962a).

ICAO Document 8087-C/925, Addendum No. 2, June (1962b).

Institute for Defense Analysis. Demand analysis for air travel by supersonic transport. Rept. R-118, prepared for FAA. December (1966).

International Organization for Standardization. Secretariat proposal for noise assessment with respect to annoyance ICO/TC 43 (Secretariat 298) 428, October (1967).

Johnson, W., The Effect of inversion waves upon sonic boom propagation. Inst. Environ. Res. Tech. Memo. ATDL-2, March (1967).

Johnson, W., ESSA Inversion-wave investigation. Inst. Environ. Res. Tech. Memo. ATDL-4, August (1967).

Lord Brabazon of Tara, Supersonic civil aircraft. House of Lords Official Report, **244,** No. 7, p. 567-572, November (1962).

Lundberg, B., Thoughts on space and supersonic aviation. Address at 13th International Air Safety Seminar of Flight Safety Found., Nov. 14-18, 1960. Reviewed in "Notes" covering the seminar.

Lundberg, B., Should supersonic airlines be permitted? *New Scientist,* **9,** 460-462 (1961a).

Lundberg, B., Some special problems connected with supersonic transport. Prepared for the IATA Conference on Supersonic Air Transport in Montreal, April 1961b

Lundberg, B., Is supersonic aviation compatible with the sound development of civil aviation? Lectures to the Cranfield Society, September 1961. Published as FFA (The Aeronautical Res. Inst. Sweden) Memo PE-12 (1962a).

Lundberg, B., Preventive measures against intolerable sonic-boom disturbances caused by civil supersonic aircraft. Presented at the 2nd International Congress of the *Association Internationale contre le Bruit,* Salzburg, May 1962b. *Die Schalltechnik,* **22,** No. 49, p. 14-21, Sept. 1, 1962 and FFA Memo PE-14.

Lundberg, B., Speed and safety in civil aviation. The 3rd Daniel and Florence Guggenheim Memorial Lecture. Proc. 3rd Int. Cong. Aeronautical Sciences in Stockholm Aug. 27th-31st 1962c. Also published as FFA Reports 94, 95, and 96 (1963 and 1964).

Lundberg, B., The supersonic threat. *The Observer,* London, Aug. 25 and Sept. 1 (1963).

Lundberg, B., Pros and cons of supersonic aviation in relation to gains or losses in the combined time/comfort consideration. *J. Royal Aeronautical Soc.,* **68,** No. 645, 611-630 (1964).

Lundberg, B., Supersonic aviation—a testcase for democracy. NATO's 15 Nations, April-May and June-July (1965).

LUNDBERG, B., DRESSLER, R., and LAGMAN, S., Atmospheric Magnification of sonic booms in the Oklahoma tests. FFA Report 112 (1967).

MAGLIERI, DOMENIC J., and HUBBARD, HARVEY H., Atmospheric effects on sonic-boom signatures. Presented at the 54th Int. Cong. Acoust., Liège, Belgium, Sept. 7-14, 1965.

NEWBERRY, C. W., Measuring the sonic boom and its effect on buildings. Materials Research & Standards, November (1964).

SAWYER, RICHARD H., and O'BRIEN, JOSEPH P., Simulation studies of the supersonic transport in the air traffic control system. SAE Report 650242 (1955).

SCHENKER-SPRUENGLI, O., Down with the decibels! *UNESCO Courier*, July (1967).

STANFORD RESEARCH INSTITUTE. Sonic boom experiments at Edwards Air Force Base, interim report. Proj. ETU-6065, July (1967).

WHITLOW, J., Airplane size and staging effects on SST cruise sonic boom. NASA TN D-4677, July (1968).

The Citizen's View

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I doubt I can do very much with my particular assignment—the citizen's view of noise in the light of current technological development, or as a public health matter.

Perhaps the citizen lets out an oath when an especially exacerbating noise afflicts him. He may roar and yelp a bit and declare that "there ought to be a law." But his roar soon subsides to a mutter and ultimately to silence, which is precisely what the noisemakers count on. Hence we have the "cacophonic republic." Today we are more a dinful than a sinful nation. While we will not tolerate marijuana on the one hand, the sputtering motorbike on Sunday afternoon and the loudly grinding garbage masticator at 6 a.m. Tuesday are accepted as part of the American way. The noisemakers remind us often of Clifford Bragdon's (1968) statement that "one man's music is another man's noise."

Some may challenge this description of the citizen's viewpoint, having in mind the several score court actions pending against assorted airport noise sources and the number of suits against other rackety nuisances around the country. I may be reminded of such doughty organizations as New York's Committee for a Quieter City and the Citizens' League Against the Sonic Boom. But as necessary and effective as such organizations may be, their concerns are specialized and sometimes local. They no more amount to the needed national campaign against noise than a commando raid on a beach amounts to a full-scale war. Indeed, considering the variety, volume, and intrusiveness of noise to which every urbanite, and an increasing number of rural dwellers, are subject the marvel is that there are so few such activities. Far from objecting to the aural beating which he daily experiences, *homo Americanus* seems to have an appetite for it. This acceptance does not at all reflect my own viewpoint.

There is yet another reason why I am a questionable choice for my assignment here: The program leaves very little for me to say. For example, I had intended to flail away about the sonic boom, but I observe that this must be a well-gnawed bone to all of you by now.

Yet in fairness to my fellow members of the Citizens' League Against the Sonic Boom, I am going to put in a paragraph anyway, not, however, of my own manufacture, because I have written so much on this topic my words are shopworn. I cite instead Garret Hardin,[1] of the University of California at Santa Barbara, whom I shall mention again later:

> . . . sonic boom . . . is something much worse than noise. Experiencing it is like living inside a drum beaten by an idiot at insane intervals. "Disconcerting" is the mildest word we can use for this experience. For invalids, for the mentally disturbed, for surgeons surprised in delicate operations, for those who want to sleep or pray . . . such a disturbance is scarcely tolerable. Every SST flight from coast to coast will disturb 20 million groundlings as it enables 400 passengers to save three hours apiece. Is it worth it?

Hardin says the answer is no; and so do I. Virtually all the other issues on my mind have been spoken on by experts who have, I imagine, indignation as sharp as my own that we should mistreat one another's sensibilities as we do.

So what I have to offer you is not the citizen's brief against the noisemakers for, as I have said, I fear this is a pallid and unconvincing plea. I will give you my personal comments, not organized into an entirely tight argument, on several aspects of the common annoyance. I shall also make a few remedial suggestions.

Civilized Standards

This conference is all to the good. I hope and expect that something will come of it but the areas of concern are a little limited. I believe that the case against noise must be made on the basis of civilized standards as much as on the basis of public health or economy. If research, for example, should definitely establish that no human or material harm was being done by the sonic boom, I would recommend a gigantic increase in the campaign against it, because sonic boom is de-civilizing. No self-respecting civilization ought to have to accommodate such an annoyance. We should not have to produce irrefutable evidence that our health is being impaired before action can be taken against the more and more numerous assailants of quiet. Economic benefits should not be conclusive in any argument between noisemakers and people. Civilized life means amenities, among which quiet and privacy rank high; and I look on civilized life as one of the principal goals of all activity here below.

I do not suggest that the highly technically oriented community to which we are irrevocably committed can be run in the quiet of a hermitage. My proposition is that we must not base our case solely, or even principally, on public health or economic grounds. There is, I fear, some tendency in this direction. The article by Clifford Bragdon from which I have already quoted is an example; I recommend it highly for it reviews soberly where we stand with respect to knowledge about noise (we don't know much) and measures of control (very few effective measures have yet been devised.)

The subheads in Bragdon's piece make my point: Effects of Noise on Health,

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[1] Making Error Creative. Unpublished paper, Santa Barbara, 1968, p. 2.

Interference with Sleep, Interference with Communication, Interference with Performance, Property Damage, Economics of Noise.

Clifford Bragdon's survey of the literature is impressive, and I commend him for concluding that

> It is a matter of establishing what importance noise control and noise abatement have relative to the other values of our urban civilization.

Yet it is precisely these other values which need emphasis just as much as demonstrations of growing deafness, stress, and the inefficiencies produced by of increasing noise. Quiet and privacy are positive values not to be considered expendable except in cases of the utmost importance. I cannot be persuaded that clatter and racket have yet supplanted quiet and privacy as American values, but I am convinced that Americans are putting up with clatter and racket in the mistaken belief that one day everything will settle down and the cacophonic republic will be no more. This is a most unlikely result, unless unprecedented steps are taken to restore the positive values of quiet and privacy.

Here, as a first point, we must assert a principle on which all depends: the "Principle of Value Elucidation and Maintenance by Elites." In less complicated words this means that there are certain things we hold in common, variously called beliefs, or convictions, or values. These are staples of our particulr brand of civilized life, our warrant of community. They often emerge as ragged cliches, as Sunday morning homiletics, or as patriotic oratory. But they are nevertheless valid and at the heart of the matter. Thus we value probity. We prize integrity, whether of person or of institution. Egalitarianism ranks high, and few persons will knock the idea of equal justice.

Yet all these values are frequently swamped by higher tides in American life. Americans do not always find it opportune to be honest or just, and they can often easily see unfortunate people as intrinsically less equal and worthy than themselves. There is general agreement on central values, but no general instrument for reminding ourselves of the presence of these values and of the need to defend them against invasions.

So the task of elucidation and maintenance must be taken up by elites. By way of immediate example: No public machinery exists to scrutinize and pull apart such social illiteracies as the current advertisement of General Electric Corporation for its SST engines, so an elite—in this case called the Citizens League Against the Sonic Boom—has assumed the job. This advertisement bears the headlines: *Faster than a Speeding Bullet: Superplane. Building engines for the SST is one way General Electric is helping keep America on the go and on the grow.* This kind of technological puffery appears in a thousand and one forms about the SST and other technical follies, each exhibiting its own kernel of anti-value.

Though it seems at odds with democratic principle, I have no hesitation in defending this doctrine. It has, in fact, little to do with democracy. Civilized life is a matter of choices, and the choices cannot be left to the ardent seekers after oil or energy who cheerfully defile nature whenever it gets in the path of their quest, or to those looking for SST contracts and other profit-hungry manufacturers of noise-generating devices.

Elites organize so that a range of choices can be considered, so that the choice of the producers and distributors need not prevail without contest. The competition is terribly uneven, for who can hope to catch up with G.E.'s boastfulness and touting of false values, all done up in six delicious colors? Yet elites exist to make the effort.

In the field of conservation—in the sustaining of anything resembling a reasonable ecological balance, in depolluting air or water—the Principle of Value Elucidation and Maintenance by Elites can de seen intensively at work. The names of the elite groups in these cases are familiar: Sierra Club, Audubon Society, National Parks Association, Living Wilderness Group; and of course Justice William O. Douglas, in this field, is an elite all by himself.

If it were not for the willingness of these elites to establish the enduring values in the Grand Canyon, wild rivers, wetlands, and wilderness areas, and redwood groves, and fight for their preservation, the United States would long ago have been delivered over *in toto* to the despoilers and to the zealots of profit. The numbers in these associations taken together probably total less than a half million. They are an elite passionately devoted to the essential value of man in nature, not man over nature. In the words of E. J. Mishan,

> the chief issue that confronts us is that of seeking to adjust the environment to gratify man's nature or of adjusting man's nature to an environment determined predominantly by "efficiency considerations," that is, by technological advance.

Regulation of Technology

And so I come to my second point, the need to regard noise not as a thing in itself, a string of cases of social measles that can be isolated and cured. Certain abatements of present nuisances are of course possible, and pending disasters like the sonic boom can perhaps be prevented. But noise is a by-product of technology, and ultimately the way to keep noise at levels consonant with civilized life is through the regulation of technology. We have been neither interested nor successful in controlling noise because we have been neither interested nor successful in coping with technology. Until we are willing to deal with the cause, fussing around with symptoms is not likely to produce far-reaching or durable results.

I do not mean to derogate any of the useful investigations into more effective abatement, medical aspects and the like. All will play their part in bringing technology to terms with the civilized life. Someone in this room may in time prove the prediction made 60 years ago by Robert Koch, the bacteriologist and Nobel Laureate: "The day will come when man will have to fight merciless noise as the worst enemy of his health." But even this may not be enough: a somewhat similar message was delivered with respect to cigarettes, and the tobacco companies are more prosperous than ever.

So I must confess to a certain hopelessness as I put before you the rousing admonition to bring technology under control. The nation is still heavily pervaded with "technophiliasm," which has been described as being "enraptured by technique." Indeed it often seems impossible to tear Americans away from their love affair with technology. Yet this is what must be done if civilized life is to survive.

Some time ago I suggested that technology is so pervasive and ominous that its regulation and direction has now become a constitutional matter. Anyone interested in this argument can look at the *Saturday Review* of March 2, 1968, in which some promising Congressional activity in this direction is described. Though I continue to believe that raising the control of technology to a constitutional level is the ultimate solution, if any solution at all is to be found, I shall conclude this argument on a lofty attitude.

Before proposing a few minor therapies for ear pollution, let me make plain the depth of my own response.

I am a hardliner about noise. I do not want to put up with explosive exhausts of motorcycles, large or small. I have spent futile hours looking for a restaurant where my waffles and bacon need not be accompanied by the syrup of Muzak. Even in my own city of Santa Barbara, which as we shall see is also capable of highly civilized action, downtown merchants and city rulers have combined to bathe the passerby in an unending shower of that oozy sound known as background music.

When, as often happens, a half dozen Defense Department helicopters whine low overhead, I yearn for a super-defense department to protect me from this needless usurpation. The incessant tinkle of the Good Humor man has put me off street-purveyed ice cream for good. Each sonic boom I take as a personal affront. I feel anger on behalf of those thousands of human beings whose bedrooms abut freeways and aircraft runways. Outboard motors on remote mountain lakes; power mowers, riveters, bulldozers, chainsaws, and their unholy kindred set my adrenal glands going with spasms of dislike.

In these multifarious offences against civilized life I recognize not only technology, but bad technology, half-technology, if you like. However well these instruments perform on their own terms, they perform badly on human terms. Their diseconomies outweigh their economies. So the few suggestions I have to offer aim mainly at the elimination of the diseconomies in familiar noise sources; that is, at either perfecting the technology so that it will not be an insult to human sensibilities and the values of civilized life, or getting rid of it.

1. The use of jackhammers, air-compressors, pile drivers, and similar noise-bearing monsters can be limited to a declining number of hours a day, so that at the end of a stipulated period they would be outlawed; and doubtless then be replaced by noiseless varieties.
2. Anyone playing a transistor radio in public can be fined $500.
3. Urban areas can be zoned as "quiet neighborhoods" where encroachment

by any kind of noisy device, be it truck, bus, garbage-disposal unit, or chattering air conditioner will be followed by enormous fines and perhaps by confiscation.

4. Restaurants can be required to provide accommodations where food can be absorbed out of range of the omnipresent Muzak.
5. Horns can be taken off all cars and trucks, and the use of sirens by ambulances and police cars forbidden.
6. Motorcycles and motorbikes can be banned; the raucous entertainment of the few must give way to the civilized life of the many.
7. Helicopter and vertical takeoff aircraft can be kept away from populated areas, on the same sound anti-sound principle.
8. Those benefiting by aircraft noise around airports, i.e., airlines and their customers, can be obliged to pay for the psychic and material effects of their activities on those woeful thousands lying in their path.
9. Sonic boom can be legislated against, nationally and locally. Some western European nations have already made it clear that they will not allow the thunderclap of the boom to traverse their lands, and Santa Barbara has led the way among American communities in banning this super-nuisance. The best way to eliminate the threat of sonic boom for once and for all in this country would be to have supersonic military planes fly over Washington, D.C. for two or three days and nights while Congress is in session. I am confident that the great SST debate would come to an abrupt and decisive halt, and we in the Citizens League Against the Sonic Boom could disband or perhaps take up a wider line of trade, like doing away with tote-goats in wilderness areas.
10. I do not know what to do about the remorseless snarling of traffic on the great highways that more and more stream through urban neighborhoods. But forbidding their use by high-speed, high-decibel trucks between 10 at night and 7 in the morning would be a good start.
11. Noise authorities can be set up in each state and city with over-riding authority to abate or ban noise, and be armed with police power to enforce their decisions.

I have presented these few proposals for a quieter and more civilized life without any accompanying argument. Some will think them merely cranky and idiosyncratic, and lacking a spirit of tolerance. Nevertheless, it must be pointed out that even if all were adopted, the effect would be only to reduce a trifle the volume of noise assaulting us and maybe to slow down the advent of new sources. My suggestions are made in good faith, as a member of the elite concerned with the deep values of civilized life, and in line with the warning issued by Vern O. Knudsen:

> Noise, like smog, is a slow agent of death. If it continues to increase for the next 30 years as it has for the past 30, it could become lethal.

If I were required to put forward some more general proposal short of constitutional remedy, I would turn again to Garrett Hardin. His formulation he calls the Frankel Program because it is based on the following statement by Charles Frankel:

> Responsibility is the product of definite social arrangements. A decision is responsible when the man or group that makes it has to answer for it to those who are directly or indirectly affected by it. . . . To create . . . a structure of responsibility in a mass society is the over-arching problem.

To Hardin the implicit Frankel Program means, for example, that the physician who prolongs the life of a human being from whom all hope has fled should also have the personal responsibility for caring for such a person, not hiring someone to supply the care, but himself providing the care.

The application of the Hardin-Frankel Program to noise is plain. Those responsible for the fabrications and use of noise-making instruments should be held personally responsible for the well-being of those afflicted by these devices. If they wish to enjoy the profits of their work, let them also bear the burdens and share in the human costs.

Once again, this may sound fanciful. It is assuredly a difficult program to envisage in action when cause and effect are as remote from one another as they are in most technical developments. But, as in the case of SST's "boombarding" Washington until Congress cries "uncle," it is an instance of trying to "make error creative," in Hardin's felicitous phrase. The object is the placing of responsibility. Such an accomplishment will not call for the abolition of technique but for the perfecting of technique so that its application does not shackle or deafen men, but helps them to a higher and more serene estate.

My argument comes down to the following: Unwanted sound is only one of the many aspects of a galloping technology threatening every part of civilized life. We shall cope with noise successfully only when we teach ourselves to direct technology to the fulfillment of man's nature. Technology today is in a half-developed and primitive state, so that it detracts as much or more from man's welfare as it adds. The urban American is thus a helpless over-consumer of noise. Technology is at present a law unto itself, achieving its authority in a mistaken mystique of progress. Technology and its by-products, noise prominent among them, have, temporarily I hope, eroded values natural to man: his sense of self-worth, neighborliness, ease, privacy, and quiet. Worship of material things, grasping after profit, self-seeking on a scale without parallel in history are all functions of technology. We have foolishly taken up the values implicit in technology without asking what simultaneously is being thrown overboard. I recognize that these are controversial statements, and to critics I can only ask that they look closely both at history and at the present scene.

I have gone far beyond the bounds of my assignment. Yet it seems to me that we must fail if we take too narrow a view. Assuring domestic tranquillity turns out to be the hardest assignment laid on us by the Preamble of the Constitution. Our ears, our sensibilities, our streets and offices, all deserve every protection from the growing tumult we can devise. But such defenses will prove futile and transitory unless by some majestic change in the national will we can see to it that the brittle aims of technique support, do not seek to supplant, the values of a truly civilized community. Among these values I number freedom from needless noise, and freedom to enjoy quiet and privacy. To this end I hope that all here will enlist in the Elite for the Elucidation and Maintenance of Values. The deep qualities in our national life that I am talking about and wish to preserve transcend the mechanics of the most artful technophile. I shall let Lewis Mumford summarize for me:

> Genuine value lies in the power to sustain or enrich life . . . the value lies directly in the life function, not . . . in the work done by human agents.

References

BRAGDON, C., Noise, a syndrome of modern society. *Scientist and Citizen,* **29,** March (1968).

Center Magazine V, Santa Barbara, July (1968).

MISHAN, E. J., *The Costs of Economic Growth.* London: Staples Press (1968).

New York *Journal Tribune,* April 23 (1967), p. 12.

MUMFORD, L., *Technics and Civilization.* New York: Harcourt, Brace (1934), p. 76.

Panel V
Community Noise Control

Opening Remarks

Stannard M. Potter

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In opening this session on community noise control, I shall report briefly on the "state of the art" and attempt to set the stage for panelists, who, in their fields, have done much for the cause of quieter communities.

Perhaps the most effective statement about how we stand on community noise control was summarized in a contemporary Federal court opinion. Judge Dooling in 63 C 1280, dated June 30, 1967, states:

> The dimensions of the noise problem cannot be minimized. It is, however, one of the manifold of environmental problems that press on a society in which the pace of industrialization steadily outstrips the capacity to deal with its modification of the total environment of urban and suburban existence.

Like so many other negative components of our environment, noise has prospered in our communities in spite of considerable public and legal complaint, many scientific conferences and reports, organized campaigns, municipal and even state regulation.

Why has the expenditure of so much time, money, and talent failed to make a dent in the acoustical insults to which each of us are exposed daily?

There are as many reasons as there are noise sources and until a massive attack on each of these emitters is successful, the chaotic cacophony will continue.

Perhaps a brief review of the practical results from some of the milestone regulatory efforts would be in order.

Take one of the earliest efforts to control noise from industrial plants, for example. In the mid-1950s, Chicago instituted a zoning ordinance which established a set of band-pressure levels limiting noise at the property line equivalent to roughly 50 dBA. For business with a social conscience, this ordinance established a guideline and many companies have designed "quiet" into their factories around this goal. That is progress!

Unfortunately, one cannot always hear that "sound of progress" for all the noise that the street traffic or construction machinery makes. The principal weakness of the Chicago zoning ordinance is that it lacks a limiting provision for all noise sources. By accepting transportation noise, it fails to quiet the community. There is secondary fallout from this provision which complicates enforcement and encourages disrespect for its intended purpose.

Since the Chicago zoning ordinance specifically exempted traffic noise, it was natural for municipalities to develop a rash of automotive and truck noise limits. The resulting hodgepode of units and levels was successfully parried by the Automobile Manufacturers' Association using its then standardized SAE Loudness Limit of 125 sones. So, progress in regulation of truck noise awaited the landmark effort of the Thruway Noise Abatement Committee, chaired by Christine Helwig, Councilman in Mamaroneck, New York. This group, armed with facts derived from noise surveys it sponsored, was able to enlist the cooperation of truck owners, state and national associations, truck manufacturers, enforcement agencies, and finally the legislature itself, to enact the first state law in the United States incorporating an objective standard limiting the noise of motor vehicles. Not only was this broad base of cooperation remarkable, but also the use of the dBA unit permitting relatively simple measurement means for enforcement purposes. While the level was compromised on the high side, the unresolved tire noise problem limited enforcement to speeds below 35 mph. This still would have eliminated trucks with "gutted" mufflers, if it were not for the actual enforcement level used in the field.

Reasoning from its experience with radar, the State Police enforce this noise limiting law between 92 and 94 dBA for good measure even though the legal limit is 88 dBA and 2 dB was suggested as a reasonable tolerance. There are very few trucks that exceed 94 dBA. This, coupled with the fact that the whole Empire State has only two sound-level meters, has limited the summonses to six in two years where the traffic exceeds 1000 trucks per hour. Obviously, not too effective!

The Hempstead ordinance, exempting no machinery noise, was more permissive for shorter durations. Under this ordinance the Dura-level was born. It relates the band-pressure level to arbitrary times, 6, 12, and 60 seconds, depending on day or night, transient or steady-state noise. Again, the same court stated:

> It is not suggested that the "limiting noise spectra" of the ordinance are unreasonably low viewed as stating sound levels above which noise is irritatingly loud when heard in private dwellings.

Though the ordinance has been enjoined through action brought by airline, aircraft, and airport interests, it is important to note that the noise limits themselves found acceptance by the court.

Another milestone in use of regulatory power for noise control has been the 112 PNdB aircraft-noise limit at three miles from start of takeoff roll established by the New York Port of Authority in the late 1950s. That such a high noise limit may be considered of dubious value was expressed in the testimony of the president of one of the nation's leading colleges: "The Port of New York Authority limit of 112 Perceived Noise Decibels is totally intolerable to me for any purpose whatsoever." It is generally conceded that the purpose of the noise limit is to show diligence on the part of the Port of New York Authority in regard to the aircraft noise in the community.

Another weakness of this regulation is that it does not specify the aircraft operation or location in relation to the monitoring position; hence, an aircraft can either be far enough away from the monitoring location or reduce power while passing the microphone and resume power over the residential community. The record of compliance, obviously, is of questionable value to the surrounding community.

Though the three legislative efforts outlined above have been effective, all noise control will not necessarily be achieved through legislation. Industrial leaders have been of the opinion that some form of compulsion or, at least, guiding standards are needed to control community noise.

Time does not permit discussion of the voluntary efforts on the part of the community and the industry to ameliorate the noise; but, in general, they, too, have failed for a variety or reasons.

With the emergence of renewed interest in our total environment, there is a new opportunity for community noise control and, in the following papers, we will have some guidance on how community noise can be controlled.

Control of Aircraft Noise at the Source

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Control of aircraft noise at the source means the following:

(1) reducing the noise level,
(2) making the noise quality less objectionable,
(3) reducing the duration of a noise event,
(4) reducing the number of events, or
(5) changing the time of day of a noise event to a time when it is less objectionable.

The characteristics of the noise event, items 1, 2, and 3, are a function of the noise characteristics of the engine and the noise attenuation of other aircraft elements associated with the engine, including the engine inlet duct, the fan discharge duct, and the engine primary exhaust nozzle. These characteristics are also a function of aircraft flight path, which is in turn a function of aircraft design and percent of maximum gross weight. The other factors, items 4 and 5, are a function of aircraft operations at a particular airport. Means for assessing the noise impact of all aircraft operations in areas near airports have been available for some time. The accuracy of these means for rating the noise of individual aircraft flyovers or events is relatively poor. While these inaccuracies are reduced when the operations of several types of aircraft at a wide range of gross weights are summed to obtain the total noise exposure of an area, other inaccuracies are introduced in the form of weighting factors for number of events, time of day, determination of number of events per day and night, etc. Studies are being conducted to improve the accuracy of these noise exposure rating scales; however, there is no reason why the best scales presently available should not be used.

So far we've referred to the factors involved in controlling aircraft noise at the source in a broad sense. A more detailed survey of aircraft noise at take-off should start with the engine itself. To obtain some perspective, we might compare aircraft to railroad passenger trains. This comparison is presented to provide some feeling for the amount of power being expended by aircraft engines during take-off and for the relatively inefficient means available to the jet aircraft for applying that power at low speed to produce thrust.

One four-engine transport at 170 knots using 15,000 lbs of thrust per engine produces 31,600 horsepower. This is roughly the power used by 12 passenger trains accelerating from the terminal. Needless to say, 12 accelerating passenger trains all within a few hundred feet would not be quiet. Also, on railroads extra weight used in low-noise designs is not such a crucial factor as in an airplane; i.e., it doesn't have to fly.

The aircraft engine produces its thrust by propelling a large mass of air rearward into the ambient atmosphere instead of simply applying torque to wheels. The lack of wheel-to-rail or wheel-to-ground traction forces the aircraft to use an air-mass-movement mechanism which inherently produces turbulence and acoustic energy. Some of this turbulence and acoustic energy is produced inside the engine as the air is forced through compressors, burners, and turbines, and some is produced outside the engine where the jet discharge impinges on or into the ambient air.

Since this paper is presented at a Conference on Noise as a Public Health Hazard, it would seem inappropriate to delve into the technical details of noise generation inside the engine and in the turbulent mixing regions of the exhaust wakes outside the engine. Nor would it seem appropriate to report on research and development efforts to reduce the noise generated by the engine. Papers on this subject are being presented in an increasing volume at conferences on acoustics and at engineering society meetings throughout the world. It would seem more desirable to present here a broad-brush treatment of the prospects for aircraft noise reduction at the souce over the next few years.

Engine Noise Reduction

Engine thrust is directly proportional to mass flow through the engine times the increase in velocity of the air flowing through the engine. Engine noise is directly proportional to the mass flow and to something near the eighth power of the velocity. An obvious design practice would be to increase the mass flow and reduce the velocity. This has been done step by step over the last few years in going from turbojet to turbofan engines and increasing the bypass ratio (the ratio of fan air bypassing the engine to engine air) of these turbofan engines to the point where noise from other sources is at a higher level than the noise from the exhaust wakes. This noise from other sources is mostly from the fan and as the bypass ratio increases the noise from the fan increases unless other changes are made in the engine. Thus, increasing the bypass ratio in the range of bypass ratios being used for the new generation of engines merely transfers the noise problem from the exhaust wakes to the fans. The latest fan designs, incidentally, incorporate refinements for noise reduction developed over the past several years, including improving noise quality by reducing the level of pure-tone noise.

To summarize the engine noise reduction situation, the new generation high-bypass ratio engines will have less exhaust noise and less pure-tone noise, with the remaining noise predominantly fan noise. Looking to the future, while we cannot predict or schedule discoveries or inspirations, it is likely that noise reduction will continue to be achieved in small pieces as a result of continuous effort applied over a long period of time. Thus, no significant change in the slow rate of aircraft engine noise reduction can be predicted.

Attenuation In Ducts

The next important area for control of aircraft noise is the attentuation of engine noise, primarily fan noise, as it is propagated outward through the fan inlet and discharge ducts. Many years of research and development have gone into the study of acoustically absorbent duct treatments. The results of this work will be incorporated in the inlet and discharge ducts of the next generation of transport aircraft. If the attenuation of fan noise by this duct treatment were large enough the noise produced outside the engine by the exhaust wakes would again be limiting. However, for high-bypass-ratio engines the exhaust wake noise levels are relatively low and the difficulty in achieving fan-noise reduction in an annular duct with a large radial dimension is relatively high. Some spectacular results have been obtained in attenuating noise from experimental, low-bypass-ratio engine installations. These results should not be interpreted as indicating that similar duct treatment will provide similar noise reductions on high-bypass-ratio engines. The maximum noise reduction is obtained when bypass ratio and duct treatment are made compatible.

Noise Units

Quantitative values for predicted noise reduction are difficult to obtain in terms of dB, more difficult to predict in terms of perceived noise (PNdB), and still more difficult to predict in terms of effective perceived noise (EPNdB). Everyone concerned, particularly the manufacturers, is interested in insuring that expensive hardware built to provide noise reduction does in fact provide some reduction in the impact of noise on people. The technical group in the U.S. working on aircraft noise has been using PNdB for some time. This group is also attempting to develop an aircraft noise rating scale (EPNdB) which takes into account the effect of pure tones and the duration of the noise flyover cycle.

Several EPNdB scales have been proposed for this purpose but attempts to validate them indicate that the best is still quite inaccurate. The calculated correction may be zero when the correction should be significant or the calculated correction may be small when it should be large or vice versa. An SAE cooperative engineering research project has been established to utilize several psychoacoustic laboratories in a research program to develop a usable scale for rating aircraft flyover noise cycles. It was estimated that this would be a two-year program.

Amount of Noise Reduction

Some indication of noise reductions to be anticipated from the new generation of aircraft may be obtained from the noise certification limits which are being discussed by the FAA and the aircraft manufacturers. The FAA has talked about an EPNdB noise reduction on the order of 10 and is proposing specific numbers in EPNdB for take-off, approach, and sideline for aircraft as a function of gross weight. There is no guarantee that these noise levels can be met. It will be necessary to make flight tests of new aircraft to find out. If the aircraft do not meet the specified limits, the FAA may permit operation for a period of years while research and development work on noise reduction is continuing.

The most difficult noise-reduction problem is the long-range aircraft. Short- and medium-range aircraft can be built to provide steeper climbout which helps reduce the noise under the flight path. However, changes to long-range aircraft to achieve the same result tend to convert the aircraft to short- or medium-range. Discussions between the FAA and industry are continuing on all of these problems in an effort to find out just how much noise reduction can be achieved and on what time schedule.

The schedule for the reduction of aircraft engine noise is not a smooth curve of x dB per year. Research and development (R and D) programs for noise reduction may involve changes in engine cycle or changes in engine geometry. While the R and D leading to these changes may be conducted over a period of years, it is usually necessary to make a new engine design which will incorporate the basic changes required to provide the noise reduction. Thus, while R and D is a continuing program, a step reduction in engine noise is available on aircraft when a new generation of aircraft engines or engine installation designs comes into being.

Community Noise Exposure

Predictions of community noise exposure are based on the summation of noise contributions by all aircraft producing noise in a given area. Some noise reduction as described above will be available as new aircraft replace current models. These new aircraft will also carry more passengers. Thus, for a given passenger-traffic the noise exposure will be smaller for two reasons: lower EPNdB per flight, and fewer flights. At airports operating at or near capacity now, the passenger and freight volume can be doubled without increasing the number of flights if aircraft with a doubled capacity are used. If these aircraft also produce lower noise levels, the airport communities will have the net benefit of the lower noise levels. At many airports operating at a smaller percentage of their capacity, however, the noise exposure can be expected to increase. New aircraft will be used on trunk lines between major cities where traffic levels are high. The displaced current aircraft will be used at smaller airports where traffic densities are not as high.

The course of community noise exposure over the next few decades is being plotted to learn what will happen if no special action is taken and what would happen if specific actions were taken. The inputs required for such plots include information on the noise characteristics of the fleet of U.S. aircraft and information on the operations of these aircraft in the U.S. system of airports. Obviously, current-production type aircraft will predominate on U.S. airports through the 1970s. Some new-generation high-bypass-ratio aircraft with an order of magnitude of noise reduction approaching 10 EPNdB will go into service in the early 1970s but they will not constitute a high percentage of aircraft in use until the late 1970s on some airports and the 1980s on other airports. Current aircraft types and these new-generation aircraft will probably predominate on U.S. airports through the 1980s and another new generation may take over in the 1990s. Predictions of aircraft traffic and of aircraft noise exposure are made by the FAA. Community planning for high noise exposure areas is being carried out by HUD. Land-use change within the 10 highest Noise Exposure Forecast (NEF) contours to uses compatible with the existing aircraft noise would reduce the maximum noise exposure by an amount comparable to a 10 EPNdB aircraft noise reduction. The HUD paper to be presented at this conference will undoubtedly describe steps being taken along this line.

Summary

To summarize the information available regarding control of aircraft noise at the source, the following points can be made:

(1) New-generation, high-bypass-ratio engines have modified and refined noise characteristics which will contribute to aircraft noise-reduction.

(2) Acoustically treated fan inlet and discharge ducts mounted on the new-generation high-bypass-ratio engines have encouraged the FAA to set 10 EPNdB noise reduction as a tentative goal for new-generation aircraft.

(3) Higher capacity new-generation aircraft will permit increases in traffic volume without increases in number of flights at airports with high density traffic.

(4) Increases in traffic density involving increases in the number of operations using current aircraft will increase aircraft noise exposure.

Cars, Trucks, and Tractors As Noise Sources

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The existence of noise as an annoyance problem is an undisputed fact of our modern way of living. The variety of noise sources have been cataloged in quasi-humorous cartoons, cited in public reading magazines, and documented in serious texts and technical papers. In the dim past, noise was largely confined to factories, mills, and foundries where it harassed the imprisoned worker. We know, from the 1929 publication date of the report "City Noise," that decades ago noise moved out of its confinement to affect great communities of people. Noise, like other forms of pollution, is a byproduct of man's gregariousness and so we find the situation of extreme pollution, including noise pollution, associated with the megalopolis. The recognition of the pervasiveness of the community noise problem is attested to by the assemblage of this conference, preceded last fall by a symposium at the Acoustical Society meeting in Miami, and to be followed in a few days by a full week's conference in Berkeley, California.

Included in the broad spectrum of community noise sources is transportation noise; under this we include noise from cars, trucks, and tractors, my assigned topic today.

This noise reaches the ears of the pedestrian, the bystander, the homeowner, and the apartment dweller, to name a few. The recipient of these vehicle noises can rightly ask the question, "Do cars and trucks have to be noisy?" City planners and freeway planners ask whether traffic routing could be planned to minimize traffic noise; legislators ask for control of this noise by their legislative efforts; and everyone asks, "What is being done, and what more can be done, to control vehicle and traffic noise?"

I will comment on "What has been done" and "What has not been done" and I will attempt to answer "What is being done?" and "What more can be done?"

During World War II the motor truck emerged as a transportation giant in the military service and in domestic support of the military effort. In the natural postwar extension of these capabilities in commerce and industry, the community became aware of the truck noise problem.

In 1954, the truck manufacturing industry adopted a voluntary new-vehicle noise specification of 125 sones measured at 50 ft, under maximum noise producing test conditions. A few years later this specification, and the related test procedure, were incorporated into an SAE Standard. This new-vehicle standard is adhered to today, with few exceptions, and of course many new trucks and buses fall well below this figure. In view of the increase in horsepower over the intervening years, I can assure you that maintaining this standard has required continual engineering effort. I can also assure you that, contrary to the viewpoint of many outside the industry, the new-vehicle specification was not set so that then-current production vehicles would conform comfortably. I can also say that as new vehicles or new power plants are developed, we find it hard to meet this specification.

"So," the recipient asks, "if this new-vehicle, 125-sone specification is so great why do we still have traffic noise problems?" This leads me to discuss "What has not been done?"

We must remember that the industry standard is a new-vehicle standard, and that once the vehicle is sold, the responsibility for maintenance is that of the owner or operator. For example, mufflers wear out and deteriorate. In order to maintain the new-vehicle noise level, mufflers which meet the performance of the original units must be used when replacements are required. In replacing tires, new or retread designs must be selected which do not broadcast tire noise for miles. Loose cargo or cargo tiedowns and hardware must be avoided so as not to add to the level of the basic truck noise. The casual observer or the motel guest is unduly annoyed because in a good many instances these practices have not been followed. We submit that if all vehicles in service on the road would conform to the manufacturers' specifications of 125 sones, the current traffic-noise problem would be one of significantly reduced severity.

Besides the 125-sone specification here are a few other things that have been done:

(1) We have developed silencing packages for engine-powered air compressors, which have the potential for abating nuisance noise at construction sites.

(2) A complementary development I read about recently is a sound-controlling housing made of rubberized fabric which surrounds rocks drills; I would expect that a similar housing could be used on pneumatic hammers which break up pavement and masonry.

(3) To control operator position noise levels, manufacturers have developed silencing packages for rear-dump trucks, loaders, and other earth-moving equipment. These silencing packages are available as customer options.

(4) At the request of John Lindsay's Task Force on Noise, General Motors has recently completed a noise reduction program on refuse collection and packing vehicles. As a result, one enemy of the city dwellers' sleep will be silenced.

And so, now to "What is being done?" Well, one thing that is being done is the passage of ordinances and laws to regulate vehicle noise. In view of what hasn't been done, this is a reasonable, to-be-expected action from legislative bodies, because by checking vehicle noise for compliance violators can presumably be identified—whatever the reason or cause of violation—and the condition corrected.

"Yes," people say, "we understand that noise laws have been passed, but what we really mean is, what is being done by the vehicle manufacturers?"

The vehicle manufacturers, through the industry's technical group, the Society of Automotive Engineers, have an active Vehicle Sound Level Committee. This committee has, in the recent past, developed and published an SAE Standard on sound levels for passenger cars, a standard on sound levels for tractors, dozers, shovels, cranes, residential lawn mowers, garden tools, and commercial equipment used infrequently in residential areas. These standards serve as noise guidelines in developing new vehicles of the many varieties indicated above. Many other standards are now being developed, including a new standard for sound levels for heavy trucks and buses and a standard for sound levels for truck cab interiors. These standards can and do serve as the basis for uniform legislative action. The importance of the uniformity of legislation to vehicle manufacturers should be clear.

What else is being done? The industry recognizes the problem of tire noise. Although vehicle manufacturers buy tires to install on vehicles, on trucks especially it is the purchaser who specifies the make of tire and tread design to be furnished. Thus, the vehicle manufacturer or dealer is in an awkward position if he too aggressively directs the purchaser toward an unwanted tire, albeit a quieter running one.

Nevertheless, the vehicle manufacturing industry recognizes that it has a stake in the problem. Two SAE Committees have considered this problem. Studies under way will identify noisy tread and retread types and will yield a meaningful test procedure. We can expect the results of this activity to produce noise specifications for tires—specifications which do not exist at the present time.

What else is being done? The problem of fan noise is being attacked; The basic problem of diesel engine noise is receiving attention.

Effective for the 1968 model year, motor vehicles were required to meet the California Vehicle Noise Law passed in 1967.

Lastly, "What more can be done?" With the increasing number of vehicles on the road and the increasing traffic density, I believe that a sweeping review of current traffic noise problems is in order. The main reason for this study would be to obtain soundly based reference data upon which vehicle noise criteria can be set. In the past we have given much consideration to the single vehicle event; now we must look at more complex situations such as noise emanating from freely flowing streams of freeway traffic, and from start-ups of lines of traffic at surface intersections. These are multievent situations. Many factors, such as the mix of cars and trucks, the variety of operating conditions, the varying locales, etc., add to the difficulty of grasping the critical parameters which need to be understood in order to make progress in the control of noise.

The auto industry has been giving serious attention and study to these diverse ramifications of motor vehicle noise situations and believes that a comprehensive program is needed to provide reference data to guide it in the design of vehicles so that noise level criteria, yet to be developed, can be met.

What more can be done? I suggest the following:

(1) The enforcement of vehicle noise sections of present ordinances and laws. Much more can be done in this area than is acknowledged.

(2) The insistence by city, state, and Federal government groups that on construction contracts which they control, quiet vehicles—earth-moving equipment, and construction, and industrial equipment—should be used. Civic-minded sponsors like utility companies could do the same. This suggestion is akin to proposals now being considered by the City of New York.

In closing, I would like to say that there are no great technical barriers to better control of vehicular noise; There is though a cost penalty, ultimately borne by the citizen for such improvements.

Architectural Design and Noise Control

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Much has been accomplished during recent years to provide products designed to produce a minimum of noise. Where these products are used there is less need to secure noise control through architectural design. For example, the modern office typewriter is extremely quiet compared to typewriters in common use just 15 years ago. But although specific products such as the typewriter have helped reduce noise levels within office buildings, the use of modern computer machinery has resulted in additional noise far more difficult to control. Even though the consumer is well aware of noise and has placed emphasis on noise control in product design, there are many sources of noise within a building which must be considered when designing.

The subject of architectural design for noise control is an extremely broad subject. To illustrate architectural design practices I have chosen a typical office-plant building as an example.

Buildings have interior and exterior noise problems. Design procedures require a thorough knowledge of the activities within the building and upon this knowledge the establishment of design criteria must be based. These criteria vary widely and are dependent upon the type of operation that is being considered: (1) In the noisiest areas, such as might exist in a heavy manufacturing plant, the criterion is based upon how continuous exposure to high-intensity noise affects hearing. (2) In less severe noise areas the criterion may be based upon requirements for adequate communication from individual to individual or by telephone. (3) Within office areas there is a further criterion of privacy if conversations relating to business matters must be kept inaudible outside of a given area. The requirements for these three basic areas of noise control are well defined and based upon much information. (4) A fourth criterion is much more difficult to define but encompasses those noises which may be considered annoying. Needless to say, the high-intensity noise produced by heavy manufacturing equipment is annoying. It is also possible that a rattling noise associated with air conditioning equipment in a quiet office area may be annoying. The definition of annoyance is highly dependent upon circumstances and the particular individuals involved; nevertheless, it is important to consider as carefully noises that are judged by their nuisance value rather than by the more exact requirements that we outlined above.

The criteria for a given area of a building are based upon information previously presented at this conference. It is necessary for the designer to relate the specific effects with the requirements of a particular building. A complete knowledge of the activities, as well as the noise sources, is required before an actual design may be accomplished. The selection of design criteria must be realistic for the given situation. Once adequate criteria have been established the architectural design may be accomplished in a number of different ways to achieve acceptable noise levels with a minimum additional expense for noise control.

An important part of any architectural design is the initial planning of the location of various types of spaces. Consideration must be given to all other aspects of building design so that the location of spaces does not affect the efficient operation of the plant. Within these restrictions it is often possible that expensive noise barriers may be eliminated by the initial layout of all spaces. For example, those areas which require the lowest ambient noise should be located as remotely as possible from areas in which high-level noise is more acceptable. The use of buffer zones for the isolation of noise can be accomplished by proper layout. For example, a building in which both office spaces and manufacturing areas exist can utilize corridors, storage rooms, wash rooms, and similar spaces to isolate the manufacturing areas from the relatively quiet office areas. Figure 1 illustrates a typical plan in which the high-noise-level areas have been properly isolated from low-level-noise areas. Connecting corridors between the areas are provided with vestibules having doors at both ends. The corridors are equipped with sound-absorbent ceilings to reduce noise when the doors are open.

Figure 2 illustrates how to further isolate noise within office areas.

Part A of Figure 2 shows a typical layout of a large office area, in which numerous operators of office machinery are to be located. Note that the desks are arranged in rows and each person is near several other persons. Part B of Figure 2 illustrates an alternate layout in which the people are grouped so that the space between groups is increased substantially with the same number of individuals in the same floor space. Within the group, partial height partitions may be installed with absorbent material placed on those surfaces near objectionable office machinery. These noise barriers reduce the noise within the group; the space between groups helps provide for isolation.

Critical noise areas within the office portion of the building should have vestibules or acceptable office activities within close proximity of the doors. For private offices particular attention must be paid to the construction of walls, the sealing of doors, and the treatment of air-conditioning ductwork.

Figure 3 shows the procedures which must be used to determine sound transmission from one space to another. Let us consider the requirement of privacy for this office space. The executive office has dimensions of 14′ x 18′, with a 9′ ceiling; it is adjacent to a secretarial office having dimensions of 10′ x 18′ x 9′; both offices are carpeted and contain acoustical tile ceilings having a noise reduction coefficient of 0.6.

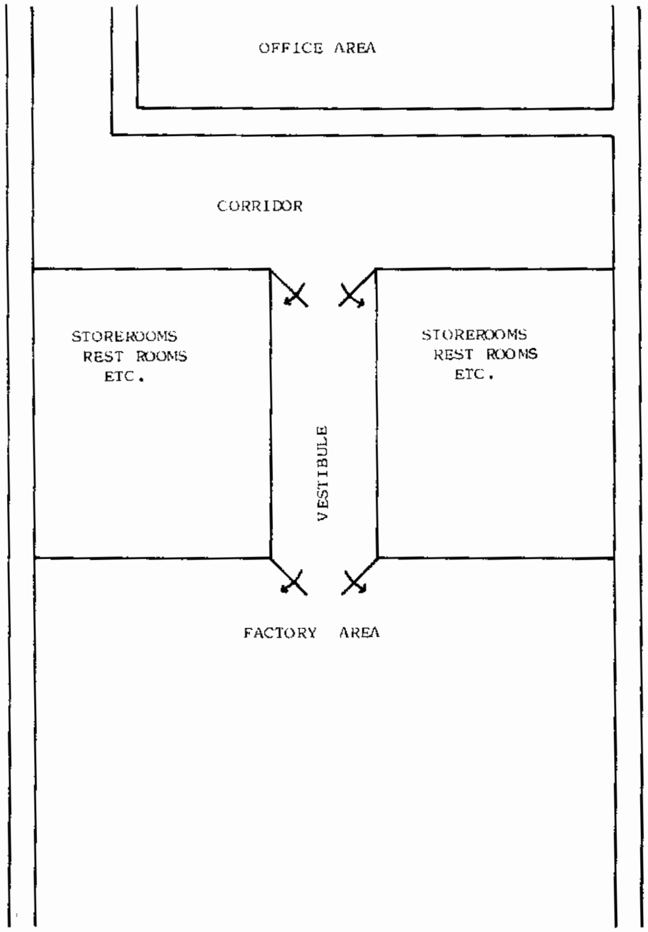

Figure 1. Isolation of noisy areas by use of buffer zones.

The objective of the design is to make ordinary speech by the executive seated at the desk inaudible in the secretarial space where visitors might be present. First, it is necessary to know the sound output of the human voice. This has been determined to be approximately 30 microwatts of power which results in a sound-pressure level (SPL) of approximately 70 dB at 1 ft from the talker. The criterion for inaudibility would be the threshold of hearing for a normal hearing person seated within the secretarial space. This has been determined to be an SPL of approximately 20 dB. The overall sound reduction between the talker and the listener must be 50 dB. If no partition were present the sound would be reduced approximately 20 dB because of distance alone. It is therefore necessary to introduce a partition which will provide the additional 30 dB reduction in sound.

The sound level at the common wall may be computed from a knowledge of the total power output of the voice and the absorption characteristics of the executive office. Because of the multiple reflection of sound by the walls,

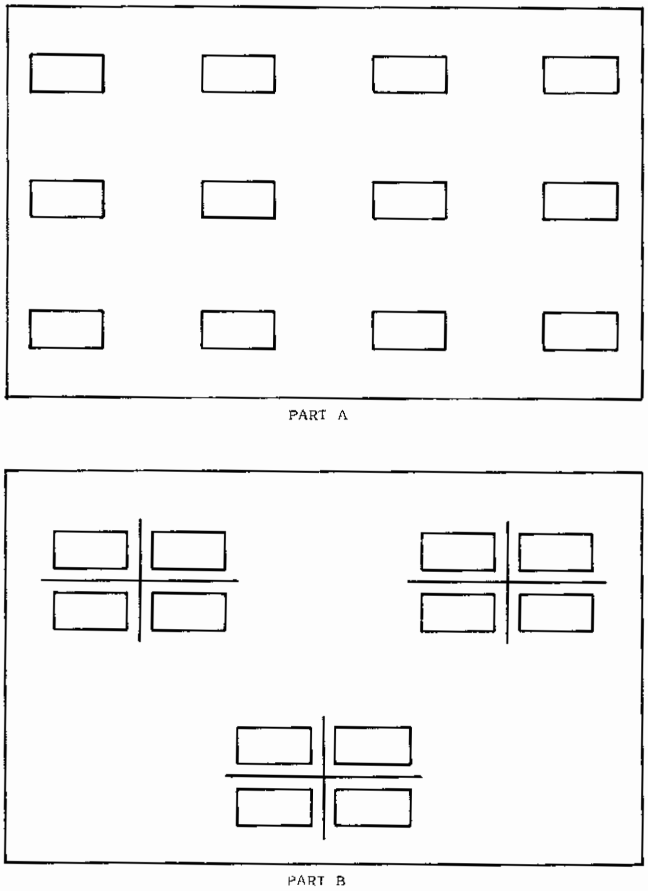

FIGURE 2. Rearrangement of desk space and use of partial height partitions to reduce interference in a many desked office.

ceiling, and floor surfaces the level is not reduced by 20 dB but only approximately 10 dB. The resulting SPL along the common wall is therefore approximately 60 dB. A reasonably good partition for this application would have a sound transmission loss of 40 dB, indicating that the sound energy is reduced by a factor of 10,000 from one side to the other side of the wall. Immediately adjacent to the wall the SPL produced would be approximately 20 dB or near the threshhold of hearing for a normal-hearing person.

Since the sound intensity is relatively uniform over the entire wall the energy transmitted into the secretarial space must include the intensity times the area of the wall. Again, it is necessary to determine the sound level within the secretarial space for a sound source which encompasses one entire wall but is reduced by the transmission loss of the partition. Even with the absorbent ceiling and the presence of carpeting, the resulting SPL throughout the room is of the order of 20 dB. It is therefore concluded that a 40-dB partition is required to reduce ordinary conversation to an acceptable level within the secretarial space.

Let us further assume that air conditioning is provided and the architect

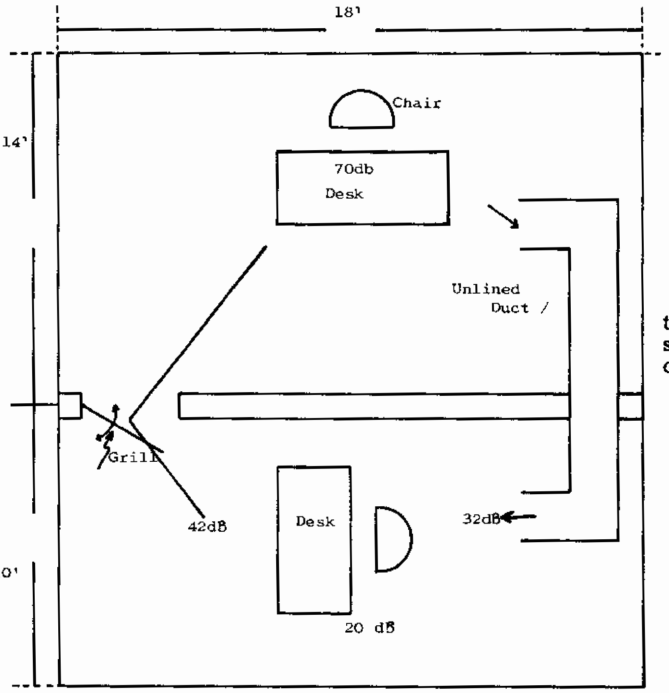

Figure 3. Sound isolation of adjacent spaces showing effect of air-conditioning system.

would like to consider the placement of a grille in the door to provide for return air through the secretarial space. If the grille has an effective opening of one square foot, then approximately 1/150th of the wall is completely open. The energy which is transmitted through this opening is more than 100 times greater than through the entire wall when well sealed. By computation, the resulting level is increased from 20 to 42 dB resulting in clearly audible speech within the secretarial space.

An alternate consideration is to provide ductwork which passes over the spaces to provide both supply and return of air. If, again, it is assumed that the ductwork has a cross-sectional area of one square foot and is further provided with 90° bends, the anticipated attenuation for speech frequencies is of the order of 10 dB. The resulting level is therefore 10 dB less than would be provided by the return air grille in the door. Even so, the SPL of speech produced in the secretarial space will be 32 dB, or 12 dB above the threshold of hearing.

Therefore it can be seen that the inclusion of air conditioning requires that special attention be given the ductwork between the two spaces to achieve the level of reduction provided by the selected partition. Although the air conditioning system has been selected as an example, care must be taken when installing electrical outlets or making any other possible openings which might allow sound to be easily transmitted from one space to another.

In our example (Figure 3) it is assumed that the common partition extends from the floor to the ceiling slab. Common practice has introduced the use of partitions which extend to the acoustical tile ceiling but provide a continuous opening above the tile ceiling. Such partitions provide an additional path of sound through one ceiling, over the partition, and through the adjoining ceiling. The characteristics of such sound propagation have been extensively studied and measurements of the performance of various types of installations are included in the *Bulletin of The Acoustical Materials Association.*

How to provide adequate control of noise transmission through air conditioning ductwork is covered in publications of the American Society of Hearing, Refrigerating and Air Conditioning Engineers.

The control of noise within plant areas involves the use of similar practices. The location of various pieces of machinery which contribute to the noise level should be considered in the basic plant layout.

Isolating activities by the use of partitions should be considered wherever possible.

Using acoustically absorbent materials will aid further in the reduction of noise transmitted from one area to another. Partial partitions containing absorbent material may provide a noise shield for particular pieces of machinery.

In addition to noises within a building, consideration must be given to noises which may result in complaints from neighboring buildings: for example, noises from air conditioning cooling towers, and loading docks. When sufficient land is not available exterior barriers should be erected to help contain noise.

Plant activities as well as the noise reduction must be taken into consideration when erecting barriers. Criteria for external noises may be obtained from city zoning ordinances currently available in many cities throughout the country. Proper exterior design in the beginning can eliminate corrective expenditures later.

Control of Noise Through Laws and Regulations

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The purpose of this paper is to comment upon noise control through laws and regulation: to consider some relevant responses of Federal, state, and local legislation and case law.

Noise control by means of laws and regulations involves balancing the rights and remedies of the individual against the rights and remedies of society.

For practical purposes, noise control can be considered in three parts: (1) the rights of a complainant against the noisemaker; (2) the duty of a noisemaker to a complainant; and (3) the relationship of Federal, state, and local legislation and case law to achievement of a proper balance between the first and second considerations.

Of the complainant's rights against the noisemaker, it should be recognized that, no matter if the noisemaker is a private person or the government, it is more difficult to deal with noise disturbance than with many other nuisances because it is largely subjective.[1] [Notes begin on page 336.—EDITOR.]

In balancing the rights of the complainant against the noisemaker it may be well to keep in mind two major principles: (1) Each person must put up with a certain amount of annoyance, inconvenience, and interference. (2) To determine the amount of annoyance, inconvenience, and interference that must be tolerated, the gravity of the harm to the complainant should be weighed against the utility of the conduct of his troublesome neighbor (noisemaker).[2] In other words, courts and legislatures are called upon to weigh the harm that is being caused to the plaintiff (claimant) by the annoyance, against the reasonableness of the defendant's conduct. Also to be considered is the detrimental effect, including considerations such as safety and cost, that would be caused to the defendant (and sometimes to the public) if the defendant were forced to discontinue the activity that produces the disturbance.

One remedy sought against the noisemaker is an injunction, brought in many cases by an individual complainant and in some cases by a class or group of those disturbed by a particular noise. More often, however, claimants disturbed by what they regard as excessive noise have sought as an alternative an award of money damages against the noisemaker.[3]

One example of the relationship between the complainant and the noisemaker may be found in a brief discussion of airport noise litigation. Airport noise suits have traditionally been based upon legal theories such as trespass, taking (eminent domain), nuisance, and constitutional damaging.

The trespass theory presents difficult problems relative to proof of physical invasion of the landowner's property. A condition precedent to recovery under this theory would be invasion by the aircraft of the landowner's property (the airspace zone directly above his land). Moreover, difficulty in pleading may arise under this approach because the operator of the particular air flight would have to be named as a defendant and only the owner immediately below the flight could maintain the action.

The nuisance theory necessarily involves the weighing of the complainant's interest in peace and quiet against the interests of the noisemaker (defendant) and of the public. It is with respect to the airport noise litigation illustration that the doctrine of "legalized nuisance" has particular relevance. This doctrine was stated in workable and useful terms by Lyman M. Tondel, Jr., as follows:

> . . . where a public or quasi-public enterprise, like a railroad, or a power plant or gas works, or a sewer system, or any irrigation system, or thruway or an airport, or the like, is expressly authorized by legislation, nuisance claims that arise out of its proper operation are to be denied. The theory is that even if the activity in question would, if privately conducted, constitute a nuisance, it has been legalized by the legislative body which, within constitutional limits, authorizes the particular conduct on behalf of the public.[4]

Mr. Tondel states that a survey of all the public airport cases in the last 10 years shows only two cases in which the nuisance theory was considered a proper basis for recovery. Thus, he concludes that this theory, although expressed and referred to as such in most complaints in this field, has had little success.[5]

The United States Constitution affords protection to each citizen against the taking of his property without just compensation. According to early common law, the claim of title to the landowner's property extended to the universe above, as well as to the boundaries of the land below (*ad coelum* theory). As a result of the increased demands upon aviation, however, the courts of the United States have declined to recognize this theory, considering airspace a "public highway."

It was not long before the Congress specifically declared that the Government has a right of free transit in our navigable airspace, which shall include "airspace needed to insure safety in take off or landing of aircraft."[6] American courts, nonetheless, continued to recognize the landowner's right to just compensation for a "taking" of his property for public use. In the famous 1946 decision in *United States* v. *Causby*,[7] the court held continuous flights of military aircraft over landowners' land, so frequent and at such low altitudes as to destroy the beneficial use of their farm, to be a taking of their property which required just compensation under the Fifth Amendment.[8] With the *Causby* case the Supreme Court put an end, once and for all, to the ancient maxim of *ad coelum* ownership. The Court said that ownership to the sky had no place in the modern world.[9]

The constitutional taking theory, which has been increasingly relied upon by attorneys is perhaps most significant.[10] The question of what constitutes a taking becomes a key one in light of the *Causby* decision.[11]

Sixteen years after the decision of the United States Supreme Court in *Causby*, the Court in *Griggs* v. *Allegheny Airport*[12] extended the liability for the "taking" to the operator of the airport. The property owner sued Allegheny County (operator of the Greater Pittsburgh Airport) and recovered under the Federal Constitution's 14th Amendment on the basis of a taking of an aviation easement over his land. The defendant airport operator argued reasonably, but unsuccessfully, that if there was a taking, Congress had placed liability on the shoulders of the Federal government when it granted it the right of free transit. In upholding the suit of the landowner, the court reasoned that the airport operator must first acquire an easement of flight. The court said that it is the airport operator who causes the interference, that the government takes nothing, and that it is the local authority which decides whether or not to build an airport, and where it is to be located.[13]

In *Griggs*, flights over plaintiff's country home were said to be "regular and almost continuous" at altitudes between 30 and 300 feet above the house. The disturbance was considered so great that plaintiff's family moved from their home, which they testified was rendered undesirable and unbearable for their residential use. In my opinion the fact that in both *Causby* and *Griggs* the plaintiffs found it necessary to leave their land because it was substantially unfit for residential use is significant.[14]

Post-*Griggs* decisions of Federal courts continue to require overhead flights as a precondition for taking of the landowner's property. Whether the U.S. Supreme Court will interpret interference resulting from lateral as well as overhead flights as a taking as post-*Griggs* decisions in an increasing number of state courts have done is not clear.[15]

What is clear is that, in addition to proving low and frequent flights, a plaintiff must show that as a result of the flights there has been a substantial if not complete deprivation of the use of his property.

The effect of the foregoing decisions will be influenced by whether or not the State Constitution of the state in which a claimant resides has provision for compensation due to a damaging of his property as well as a taking.[16]

From the foregoing case law discussion at least these conclusions may be drawn: (1) A nuisance caused by operations of the government or a body operating under governmental authority and resulting from noise does not constitute a taking, notwithstanding the fact that it causes a devaluation in market value of adjoining property. This premise also assumes that there is no showing of negligence with respect to the source of the noise. (2) The foregoing conclusion represents the Federal rule, the common law rule, and the rule of those states with constitutional language following the Federal pattern of compensation for a taking. (3) Those states which have a constitution that provides for compensation for property damaged as well as taken will permit broader recovery against the government for the nuisance (noise).

Case law represents only one part of a four-part approach to the problem of regulation of noise control through the law. Decisions must be read and their effect interpreted in the light of existing and proposed legislation on a Federal, state, and local level.

Regarding regulation on the Federal level, we have already seen the significance of the Federal Aviation Act of 1958.[17] The Federal Aviation Agency, which is greatly interested in safety and noise abatement, requires that each particular model or make of aircraft receive an "airworthiness certificate," which specifies the conditions under which the aircraft may be used in air transportation. In addition, the FAA requires that an airline receive an "air operating certificate" before it may operate a given aircraft and schedule service at a particular airport.[18]

It is clear that the FAA has, under the Federal Aviation Act of 1958, full power to prescribe air traffic rules for the "protection of persons and property on the ground," including prescription of air traffic rules in the interest of noise abatement.[19]

The FAA, in exercising its statutory authority, has set noise limits for jet airplane takeoffs (but not landings) and has adopted flight procedures at Kennedy International and other public airports, including the adoption of preferential runways systems.[20] Moreover, the Federal government has in operation an active noise abatement program with a dedicated and technically sophisticated staff.

The emphasis of the Aircraft Noise Alleviation Program under the FAA, now combined with the new Department of Transportation (DOT), has been to develop programs to reduce noise exposure to a minimum and to improve the capabilities of noise affected communities in the vicinity of airports to more effectively cope with their respective aircraft noise programs. Government expenditures to reduce the noise problem have advanced from $100,000 in 1961 to a 1.3 million authorization for FAA alone in 1965. FAA, in addition to working with DOT, is working with other agencies including HUD for a solution to the problem. Nonetheless, it has been difficult for those interested in noise abatement to awaken Congress to the need for real action.

There have been some recent signs of progress in this area. The Subcommittee on Transportation and Aeronautics of the House Interstate and Foreign Commerce Committee continued hearings in the current session of the 90th Congress on a bill introduced by Harley O. Staggers in the House of Representatives and Warren Magnuson in the Senate.

The Staggers bill, H.R. 16127, and the Magnuson bill, S. 3591, would add a new Section 611 to the Federal Aviation Act, to authorize the Administrator of the FAA or the Secretary of Transportation to prescribe and apply noise control standards and to authorize their enforcement in the same manner as safety standards are enforced.[21] Under the proposed legislation, noise output would be required to be taken into account not only in the operation of the aircraft, but at the appropriate stage of the development in manufacture of the new aircraft.

The Administration bill which was submitted at the commencement of the 90th Congress differs from the foregoing only in that it made explicit that the phrase *aircraft noise* includes "sonic boom" and the new noise authority is vested in the Secretary of Transportation rather than the Administrator of the FAA. The proposed legislation would compliment the existing authority conferred by Section 307 (c) of the Federal Aviation Act which is properly construed as authorizing the promulgation of air traffic rules and regulations governing the flight of aircraft for the protection of persons and property on the ground from aircraft noise and sonic boom.[22]

On May 17, 1968, the House Interstate and Foreign Commerce Committee included a provision to the Administration bill, thereafter reported out of Committee, that could require existing aircraft or engines to be equipped with any noise reducers that might be devised. The bill, as amended, directs the Federal Aviation Administrator and/or the Secretary of Transportation to write or recommend standards to abate or control aircraft noise and sonic boom. He is further empowered to certify aircraft in order to accomplish this.

While airline reaction was reported to be strongly against this last-minute provision included in the committee bill, the legislation passed the House of Representatives June 10, 1968, by a vote of 312 to 0 and passed the Senate by voice vote. It was signed into law by the President July 12, 1968.

In an effort to limit issues, many areas of case law and legislation bearing on noise control have not been the subject of this paper. One such collateral but extremely significant area is that of Federal and state power and influence to effect compatible land use. This subject suggests comprehensive analysis of zoning and the interrelationship of Federal, state, and local laws.[23] Briefly and oversimply, the aircraft noise control problem may be considered from two distinct points of view: (1) the noise which is produced from the operation of the aircraft itself; and (2) the effect of the aircraft noise upon the people on the ground.

Putting aside for the moment the fact that the primary source of aircraft noise is the engine, there are three broad approaches which may be utilized to achieve relief from excessive aircraft noise: (1) Move the noise away from the people. (2) Move the people away from the noise. (3) Lessen the amount of noise produced by the aircraft. Zoning and land-use problems are particularly involved with the first and second approaches.[24]

Notwithstanding the immense problems which exist as a result of present jet service, the threat of additional noise horror looms in anticipation of the proposed jumbo-jets and supersonic transports. Complex legal problems presented in new forms with respect to control in this area will demand careful consideration and sound judgment on a case-to-case basis.

While considerable attention has necessarily been drawn to the legal problems of aircraft noise reduction and respective legislation and litigation, one must not overlook the state and growth of the law concerned with control of other noise sources.

Aside from the proposed Federal legislation mentioned earlier specifically related to aircraft noise control, it is significant to note that on April 21, 1966, a Representative from New York, Theodore R. Kupferman (R., N.Y.), introduced in the House of Representatives the first bill to comprehensively deal with the problem of noise in general.[25]

Kupferman's bill, reintroduced in the 90th Congress, 1st Session, January 18, 1967, as H.R. 2819, and referred to the House Interstate and Foreign Commerce Committee, would establish an Office of Noise Control within the Office of the Surgeon General under the Department of Health, Education, and Welfare. This, in my opinion, is where it should be because general noise should be considered a health problem. The noise control office, headed by a Director and assisted by a Noise Control Advisory Council, would provide grants in aid for state and local governments to research ways and means of control, prevention, and abatement of noise.

Moreover, the bill specifically provides that the Office of Noise Control would cooperate fully with existing Federal agencies and departments presently working in the field of jet noise abatement. One of the primary functions of the Office of Noise Control would be to act as a national clearing house for general and specific noise information. It could, upon request, disseminate the wealth of its accumulated knowledge to state and local governments to help them control noise at its point of origin. The Office of Noise Control would serve a similar research and educational function with respect to noise from all sources, as the National Aircraft Noise Abatement Council, a private, nonprofit council of aircraft-industry representatives, presently serves in the field of aircraft noise abatement.

To date the House Interstate and Foreign Commerce Committee's Subcommittee on Transportation and Aeronautics has not reported Kupferman's bill out of Committee.

As stated above, one of the primary functions of the Kupferman bill would be to cooperate fully with state and local governments in their programs for noise control. Of course, one of the problems has been that state and local governments have been hesitant in initiating adequate programs. Many state and local governments have no laws dealing with the problem of general noise control; nor do they have any kind of programs to study the problem and to draft such laws. New York, to my knowledge, became in July 1965, the first state in the United States to enact a state highway anti-noise statute.[26] This law provides a measurable noise limit which can be enforced against motor vehicles creating excessive or unusual noise. The Act defines as excessive noise "... a vehicle which produces a sound of 88 decibels or more on the A scale." 90 decibels on the A scale, therefore, is a level at which violations would be charged and arrests made.[27] The noise is measured at roadside toll stations where trucks pass at speeds of less than 35 miles per hour. California recently adopted comprehensive anti-highway noise legislation that would prohibit noise levels in excess of 82 dBA for passenger cars and 92 dBA for trucks and buses.[28]

Most states have motor vehicle statutes or codes dealing with the requirement of mufflers on automobiles and trucks to prevent excessive or unusual noise. These statutes, however, usually fail to spell out quantitative measures in decibels at which violations would occur. Thus the statutes are for the most part extremely difficult to enforce and are therefore usually not enforced.[29]

There are situations where a joint response from several states is required to effectively control an environmental problem. The joining of several states in a regional response to the noise control problem has not been forthcoming, with the notable exception of the New York Port Authority.[30] The New York Port Authority governs aircraft operation procedures at Kennedy International, LaGuardia, Newark, and Teterboro airports.

Unfortunately, we have not learned as quickly as we should have from the disasters which have resulted in our failure to adequately deal years ago with the problem of air and water pollution. A regional approach combining the talents and money of several states should be considered in a common effort to establish research and development programs directed toward the alleviation of excessive noise from sources other than aircraft. For example, there is no reason why states could not join together to provide uniform motor vehicle statutes that quantatively spell out the levels at which violations would occur. A comprehensive motor vehicle statute could be uniformly adopted by all the states patterned after that of New York or California, except that more sophisticated means of measurement and enforcement must be provided.

Uniform state and/or city codes could also be enacted concerning requirements in construction and maintenance of housing and the problem of elimination of airborne and structure noises. Of course, it would be important to coordinate the efforts of the Federal government with the statutes of the states.

A good example of the responses of a large city to the complex problems of urban noise is seen in New York City. For decades it has had a basic code which contains language prohibitive of excessive noise in several areas.[31]

It is at the city code level that noise sources of garbage collection,[32] construction noise,[33] motor vehicles, loud speakers, and many other noise sources can be effectively controlled.[34] It is important, however, to exercise extreme caution when attempting to solve the problem by simply passing a law. We should inquire first whether all is being done to deal otherwise with the problem.

Much could be done to abate noise, for example, by construction companies. Noise muffling techniques, such as mufflers for foundation blasting and use of special steel wire blankets would help. So would the use of quieter methods of bolting, and planning demolitions for weekends and hours when offices normally are closed. The cost of such abatement equipment and procedures is not necessarily prohibitive. To illustrate: a simple device designed to quiet an air compressor costs about $200.00. It should be noted, however, that while the cost of abatement equipment and procedures is not necessarily prohibitive, contractors may find that union work and wage agreements, the unavailability of supporting services on weekends, and the effect of some local ordinances (Sunday Blue Laws) may cause a substantial increase in the overall job cost, thereby reducing the margin of profit to the point that precludes the consideration of noise abatement procedures.

Uniform building codes should be enacted and enforced to require the demolition contractor to reduce the building to be removed piece by piece, rather than by massive demolition. One practical way of reducing excessive demolition noise is to use outside trash chutes or else require that rubble be removed from high portions of a building by a hoist.

An interesting new method for reducing construction noise has recently been devised by Con Edison in New York. A Road-Bor machine called a "cookie cutter" can cut through a five-foot diameter into 15-inch thick asphalt and concrete with three times the speed and one-third the noise of the conventional pneumatic jack hammers. Consider how many manholes are dug each year in our cities and the noise reduction value of the "cookie cutter" quickly becomes apparent.

Steps, if voluntarily taken, remain the most feasible method of approaching the noise reduction problem in the construction industry. But if the steps are not voluntarily taken, there is no alternative but to legislate mandatory controls. If this must be done, the regulation must be fair, gradual, and uniform wherever possible. It is my view that industry should first be given the opportunity to take their own steps, but should be firmly advised by government that if their action is not forthcoming, regulation will be.

A great deal depends upon education. If the public is made aware of the detrimental effects of excessive noise it may eventually demand quieter products and quieter jobs. If public demand produces a market for quieter jobs and quieter products, industry will in turn compete to produce both at less cost. Thus, automobiles, trucks, lawn mowers, sewing machines, vacuum cleaners, hair dryers, dishwashers, air conditioners, heaters, and the like could all be quieter—and without laws or regulations dictating the reduction of their noise.

In New York City, the Polytechnic Institute of Brooklyn has been working on proposals which would include provisions in the New York City Building Code for the abatement of noise in multiple dwellings. In addition to reducing the amount of airborne noise between adjacent apartments and hallways and reducing "impact noises" between apartments, the proposed Polytechnic Code seeks to control structure-borne noises originating in moving machinery and equipment, as well as noise reaching apartments from equipment located on adjacent buildings.

Perhaps when New York adopts a building noise code other states will follow its lead and write controls into their codes. If the public expresses its desire to have quieter buildings without a substantial increase in cost by supporting uniform noise controls in building codes, the building industry will soon be forced to find materials on a nonprohibitive cost basis that will not compromise safety but will insure less noise.

Another area deserving national and state remedial attention is minimum uniform noise control standards for industrial workers. In fact, the entire noise problem as it relates to industry is of great significance. Since this topic has been discussed by panelist Edmund D. Leonard ("Control of Industrial Noise Through Regulation and Liability"), it will not be considered.

In arriving at a balance between individual rights and remedies and the rights and remedies of society it is important to attempt to define the duty of the noisemaker to the complainant. As previously mentioned, this is made difficult by the subjective nature of noise disturbance. This difficulty, however, is not new to the law. There are established legal principles[35] to depend upon. For example the law is that damages may not be recovered for a noise that constitutes a mere annoyance. Moreover, courts will not grant an injunction where undue hardship would be worked on an existing business causing noise disturbance to a claimant new to the neighborhood. But as Spater points out:

> . . . if a business under way causes a substantial decrease in the value of the plaintiff's property or a material discomfort to plantiff it will be enjoined:
> (a) if the annoyance is due to poor design or improper operation of defendant's facility and can be abated by the adoption of an improved design or operation, but the improvement must be one that is commercially feasible, or
> (b) if the activity creating the noise was established in a neighborhood obviously inappropriate for the activity.[36]

Once the rights of the claimant against the noisemaker and the duties of the noisemaker to the complainant have been fairily well defined the problem of noise control through case law becomes less difficult. An exhaustive and comprehensive review of the pertinent cases in this field is needed, together with an in depth study of existing and proposed legislation having relevance to the problem of noise control on all levels of government.

Some conclusions seem apparent when reviewing the broad field of noise control through laws and regulations:

First, it is helpful to consider the response of the law to the problem from at least four points of influence: (1) case law, (2) Federal statutes, (3) state statutes, and (4) local laws (county, city, town, and village). None of the case holdings or language of the statutes or ordinances at the various levels should be read in a vacuum. Each factual situation (noise disturbance) demanding a remedy must be considered unique unless a pattern is clear.

Second, with respect to aircraft noise reduction, additional Federal standards are necessary and will be forthcoming. The Federal government will be forced to assume increasing authority and responsibility for noise control, especially in areas where it has pre-empted the field. Fact patterns squarely within the *Griggs* decision will permit recovery against the owner-operator of an airport but not the Federal government.

Third, the real frontier to be explored in noise pollution is general noise reduction and control (not limited to aircraft). More study is needed in this area on all levels of government and industry. Educational efforts should precede regulatory efforts. Voluntary acceptance of control measures should come ahead of mandatory controls. Legislation such as the Kupferman bill is needed. The Federal government should aid the states and local governments to initiate their own programs.

Fourth, any statute or ordinance controlling noise should include quantitative measures or standards. Sophisticated measurement procedures should be applied. Lawyers should look outside their profession to those with acoustical engineering and scientific expertise for help in working out practical and enforceable statutory controls.

Fifth, in balancing the rights of an individual disturbed by a particular noise against a government-authorized activity causing noise (nuisance) and deemed essential and free from negligent operation, the government activity will prevail. Recoveries against the government for nuisance will be broader under states with constitutions containing language for compensation for damage as well as a taking of property.

Sixth, everyone must tolerate noise to some extent. To what extent must be determined on each set of facts and circumstances. More can be done to abate noise than most people presently realize. We must face the noise pollution problem immediately and squarely, and allocate whatever funds, energy, and talent are available to place this serious environmental problem under control.

Notes

1. See *Spater,* George A., "Noise and the Law." 63 Mich L. Rev 1373 (June 1965). Certain noises, however, can do visable physical damage, the best known being the ability even at low volumes to break glass. Scholes, *The Oxford Companion to Music,* 6, 14, (8th ed. 1950); Spater *supra*, p. 1374, footnote 4.

For some time noise has been most commonly and simply defined as an unwanted sound. The subjective quality of noise has often been described by the classic phrase, "One man's music is another man's noise."

2. Restatement of the Law of Torts. Vol. 4, Sec. 822, comment on clause (d), Sec. 826 (1939); language adapted by this writer.

3. Injunctive relief has been largely unsuccessful in suits against public airport owners and operators for several reasons: (1) public necessity and convenience usually outweigh private or individual interests, the rationale being the fact that the air transportation industry serves a vital function and ever-present demand; (2) the Federal government has pre-empted the field of air traffic control. See ***Allegheny Airlines*** v. ***Village of Cedarhurst*** 238 F. 2d 812, 815 (2d Cer. 1956) in which the court stated that "The Federal regulatory system . . . has pre-empted the field (of air traffic) below as well as above 1,000 feet from the ground." Finally, the courts have utilized the legal fiction of "legalized nuisance," discussed later in this text and footnotes, to justify the conduct of the air transportation industry which produces the noise, and the attitude of the Federal government which reluctantly allows the disturbance.

4. See Tondel, Lyman M., Jr., "Noise Litigation at Public Airports," *Alleviaiton of Jet Aircraft Noise Near Airports.* Report of President's Jet Aircraft Noise Panel, Office of Science and Technology, Executive Office of the President (March 1966). E.g., ***Richard*** v. ***Washington Terminal Co.*** 233 U.S. 546 (1919), et al., cited:

". . . the plaintiff, whose house was approximately one hundred feet from defendant's railroad track and tunnel, brought an action to recover for damage to his property resulting from an alleged nuisance. Plaintiff suffered (1) from the noise, vibration, and smoke of the passing trains cracking the walls . . . breaking glass in the windows, and disturbing the peace and slumber of the occupants, and (2) from gas and smoke forced out of the tunnel and directed onto plaintiff's property by a fanning system. Defendant's activities, however, had been authorized by the government—its tracks and tunnel were located, constructed, and maintained under acts of Congress. There was no claim that the trains were negligently constructed, operated, or maintained.

"The Court held that the plaintiff, like all other property owners along a railroad right-of-way, was required to bear without redress the amount of noise, vibration, and smoke incident to the running of the trains. However, the plaintiff was entitled to compensation to the extent he was damaged by the fan arrangement which artificially concentrated gas and smoke on the plaintiff to a degree not shared by other property owners . . . and this, without, so far as appears, any real necessity existing for such damage.

"The general conclusion to be drawn from *Richards* v. *Washington Terminal* is that under federal law no right of action exists in private property owners for noise made by an entity functioning under authority of the government (and, a fortiori, for noise made by the government itself) even though the noise may cause a decline in the value of affected property. In such circumstances both damages and equitable relief are denied.

"It is necessary, however, to qualify this broad rule somewhat by two limitations: first, the activity being performed by the government or government-authorized entity must be sanctioned by law; second, the facility creating the noise must be properly designed and operated and in certain limited cases a government authorized entity will be held responsible when it has not properly located the facility."

Quoted from Spater *supra* note 1 at p. 1382; See *Portal Civic Club* v. *American Airlines, Inc.,* 39 Cal. 2d 708, 394 P. 2d 548; 9 AV. Cas. 17,156 (1964).

5. Of the six public nonmilitary airport cases where damages have been recovered in the United States over the last 10 years, five recoveries involving a total of $71,584 were against civil airport operators on a constitutional taking theory. In addition $690,670 has been recovered in this 10 year period in 21 cases brought against the U.S. Government where cases involved military airports. Twenty of these 21 recoveries were on a constitutional taking theory and one, *Weisberg* v. *United States,* 193 F. Supp. 815 (1961), for $750, was on a negligence theory. Mr. Tondel states the following:

". . . one reason for the greater success that plaintiffs have had against the United States is that in many cases the government has admitted a taking, leaving only the amount of compensation."

Quoted from Tondel *supra* note 4 at pp. 123-4. In *Anderson* v. *Lockheed Aircraft Corp.,* 1955 U.S. & Can. Av. 182 (Cal. Super. Ct., Los Angeles County, 1955, which involved a public airport only in a technical sense, $12,500 in damages was recovered. In another case, which arose in Georgia, the court held that the complaint stated a cause of action, so that the case should not have been dismissed on the pleadings. *Chronister* v. *City of Atlanta,* 99 Ga. App. 447, 108 S.E. 2d 731 6 Av. Cas. 17, 448 (1959).

6. Federal Aviation Act of 1958, 72 Stat. 737, 4a U.S.C. Sec. 1301 (24).

7. 328 U. S. 256 (1946). See Tondel *supra* note 4; The Court in *Causby* said at p. 266, "The airspace, apart from the immediate reaches above the land, is part of the public domain."

The Federal Aviation Act *supra,* note 6, Sec. 104, states:

"There is hereby recognized and declared to exist in behalf of any citizen of the United States a public right of freedom of transit through the navigable airspace of the United States."

Sec. 101, Subdiv. 24, of the Federal Aviation Act defines navigable as that

". . . above the minimum altitudes of flight prescribed by regulations issued under this chapter, and shall include airspace needed to insure safety in takeoff and landing of aircraft."

For a recent case where the court allowed only nominal damages for a suit based upon the trespass theory, and even that decision was reversed on appeal, see *Cheskov* v. *Port of Seattle,* 55 Wash. 2d 416, 348 P. 2d 673, 6 Av. Cas. 18, 176 (Tex. Civ. App. 1964).

8. 328 U. S. 256, 259 (1946).

9. Tondel, *supra* note 4 at p. 124, 328 U.S.C., at 261.

10. See Goldstein, Sidney, "Legal and Practical Limitations on Noise Control Methods," Report, Committee No. 4, International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, London (November 1966). For more detailed treatment of this subject by the same author see Goldstein, Sidney, "A Problem in

Federalism, Property Rights In Air Space and Technology," *Alleviation of Jet Aircraft Noise Near Airports,* Report of the President's Jet Aircraft Noise Panel, Office of Science and Technology, Executive Office of the President (March 1966).

11. In it the court held that there had been a taking when it had been found that overflights and landing and takeoff procedures were so frequent and at such low altitudes that the beneficial use of the plaintiff's farm had been destroyed. Damages were awarded plaintiff in subsequent proceedings for loss of about 150 chickens which had flown into the walls and killed themselves from fright resulting from the lights and noises of the aircraft during takeoff and landing procedures.

12. 363 U. S. 84 (1932). See also 30 Fordham L. Rev. 803 (1962) 57 N.W. U. L. Rev. 346 (1962)3; 1962 Ill. L. F. 274; 24 U. Pitt. L. Rev. 603 (1963); 63 Mich. L. Rev. 1373 (1965).

13. 369 U. S. 84 (1962); Goldstein *supra* note 10. In *Causby,* Suit was filed in the Court of Claims against the United States, which was both airport manager and airline owner. Subsequent litigation, however, encountered difficulties with which the *Causby* holding was not faced. The question became which party to sue; the airport manager, the offending airline, or the United States, who, after all, was responsible for approving the flight path. This problem was not fully solved until *Griggs* v. *Allegheny County supra* note 12.

14. For cases subsequent to *Griggs supra* note 12, which illustrate recent judicial language with respect to theories of "taking," "nuisance," and "trespass," see among others: *Batten* v. *United States,* 306 F 2d 580 (10th cir 1962), cert. den., 371 U. S. 955 (1962) rehearing den., 372 U.S. 925 (1963). This case is especially significant because it denied plaintiff the right to recover even though damages were proven. The court found no taking where military flights were not overhead. Case notes on *Batten* among others include 49 Cornell L. Q. 116 (1963); 29 S. Air L. & Com. 72 (1963); 24 Ohio S. L. J. 579 (1963). See also *Kettelson,* Ernest S., "Inverse Condemnation of Air Easements," 97 R. Prop. Prob. and T J 101 (Spring, 1968). Whether the result would have been the same if plaintiff had brought its cause of action under the Federal Tort Claims Act (28 U.S.C. 1364 (b) on the theory of wrongful conduct of the government (in allowing the noise disturbance from the planes during warm up and take off) rather than under a taking theory is questionable. The Federal Tort Claims Act is not relevant to this discussion, generally, because its coverage includes only those complaints formed in theories of nuisance or negligence, thereby excluding trespass and eminent domain. C. F. Tucker Act, 28 U.S.C. 2401. See *Thornburg* v. *Port of Portland,* 233 Or. 178, 376 P. 2d 100 (1962). In *Thornburg,* the Oregon Supreme Court described a taking as follows:

"The idea that must be expressed to the jury is that before the plaintiff may recover for a taking of his property he must show by the necessary proof that the activities of the Government are unreasonably interfering with his use of his property, and in so substantial a way as to deprive him of the practical enjoyment of his land. This loss must then be translated factually by the jury into a reduction in the market value of the land."

For case note discussion of *Thornburg* see among others 1963 Duke L. J. 563; 41 Texas L. Rev. 827 (1963). See also *Martin* v. *Port of Seattle,* 64 Wash. 2d 324, 391 P. 2d 540 (1964), cer den. 379 U. S. 989 (1965); *Hillsborough County Aviation Authority* v. *Beniterz,* 200 So. 2d 194 (Fla. 1967).

15. *Thornburg supra* note 14; *State* ex rel., *Royal et al.,* v. *City of Columbus,* 3 Ohio St. 2d 154 (1965); See Goldstein *supra* note 10 at p. 16.

16. See *Mortui* v. *Port of Seattle,* 391 P. 2d 540, 8 Av. Cas. 18, 324 (Wash. 1964) cert. den., 399 U. S. 989 (1965). About 50% of the states have Federal-type constitutional provisions compensating for property "taken for public use." The other states provide compensation for property taken or damaged, including: Ala., Alaska, Ariz., Ark., Calif., Colo., Ga., Ill., Ky., La., Minn., Miss., Mo., Mont., Neb., N.M., N.D., Okla., Penn., S.D., Tex., Utah, Va., Wash., W.Va., and Wy. In Ala., Ky., and Penn., the "damaged language" is limited to action by municipalities and public utilities with the power of eminent domain. N.C. has no state constitutional provision governing eminent domain, but property owners there are protected by the 14th Amendment of the Federal Constitution, as well as by judicial interpretation of the State Due Process Clause. Cormack, "Legal Concepts in Cases of Eminent Domain," 41 Yale L. J. 221, 222 (1931); Spater *supra* note 1 at King County, Wash., June 29, 1960.

17. Federal Aviation Act of 1958, Sec. 307 (c), Stat. 749, (49 U.S.C. Sec. 1348 (c)., *supra* note 6.

18. 14 C.F.R. Sec. 121 3 (A), 121.97 (1956).

19. *Federal Aviation Act of 1958, supra* note 17; Federal agency authority will continue to expand in this area. See Harris Committee Report, H. Rep. 36, 88th Cong. 1st Sess (1963), and more recently, the Federal Aid-to-Airports Act, Public Law 88-280 (approved March, 1964).

20. 14 C.F.R. Sec. 91.87 (g), 93.33.33 (1965); Kennedy Control Tower Bulletin No. 63-3, as amended by No. 63-11. By altering the path of the aircraft the noise transmitted to those below is naturally reduced. This plan has been put to good use except during traffic problems or bad weather, when safety demands other flight procedures.

21. Title VI of the Federal Aviation Act empowers the Administrator to issue, amend, modify, suspend, or revoke certifications, but for safety considerations only. In the 90th Congress, 1st Session, there were 16 similar bills introduced in the House and one in the Senate. Some of these bills would, in addition, cover all aircraft problems which constitute a nuisance to the public, such as air pollution or sonic boom. One of the bills (H.R. 1398) would allow financial aid to the owner, company, or local governmental body required under the Federal law to meet prescribed aircraft standards.

22. *Status Report*: Status of the Federal Aircraft Noise Alleviation Program, June 1967, Dept. of Transportation, F.A.A., Washington, D.C.

23. For excellent treatment of this subject see Randall, Robert L., "Possibilities of Achieving a Quiet Society," and Strunck, James E., "An Anlysis of the Advantages and Difficulties of Zoning and Regulations for Chicago O'Hare International Airport," both found in *Alleviation of Jet Aircraft Noise Near Airports,* Report of President's Jet Aircraft Noise Panel, Office of Science and Technology, Executive Office of the President (March 1966).

24. See Goldstein *supra* note 10. An unsuccessful attempt by a village to enforce a local ordinance which would have prohibited aircraft flight within its boundaries at altitudes of less than 1000 feet, offered an example of the impracticability of moving the people away from the noise, is found in *Allegheny Airlines et al., Port of New York Authority et al.* v. *Cedarhurst,* 132 F. Supp. 871 (D.C.E.D.N.Y. 1955). Aff'd. 258 F. 2d 812 (2 Cir. 1956); see also *City of Newark* v. *Eastern Airlines,* 159 F. Supp. 750 (D.C.N.H. 1958); see also Randall *supra* note 23; Stephen, Pohn E., "Regulation by Law of Aircraft Noise Levels from the View Point of United States Airlines," pp. 49-63, International Conference on the Reduction of Noise and Disturbance Caused by Civil Aircraft, London (November 1966).

25. As Legislative Assistant and legal counsel to Representative Kupferman during the 89th Congress and the first Session of the 90th Congress, I had an opportunity to experience the resistance to this legislation as well as problems of drafting, economics, and agency involvement. On balance, the bill has received criticism chiefly on the basis of the unnecessary creation of an additional bureau. Its supporters, however, argue that the bill is not regulatory in nature or scope and that centralization is needed in an effort to disseminate educational information and to create and administer significant abatement programs. The bill's chief problem is the apathy and insensitivity of legislators and their constituents to the problem of noise pollution. When the problem reaches crisis proportions it will, of course, be treated with more legislative interest. It would be a welcome and economical change, however, if the Congress would take steps now to avoid what will soon be a critical environmental problem. Hopefully, our sad experiences with delay in the field of air and water pollution will serve as reminders of the cost of procrastination in the pollution field.

26. The New York State legislation was the product of the efforts and determination of many public-spirited citizens, including among others, Christine Helwig, Chairman of the New York State Thurway Noise Abatement Committee; Max B. Berking, former State Senator, and Anthony Gioffre, former Assemblyman, now State Senator.

27. According to the New York State Police Department,
"Since October 1, 1965, when Section 386 of the Vehicle and Traffic Law became effective, the Division of State Police has made 45 arrests. None of the arrests resulted in court trials. Of the 45 persons arrested, 43 of them pleaded guilty and were convicted. The remaining two cases were closed as the violators were from without New York State and could not be located after they failed to appear as a result of traffic tickets. Our enforcement and judicial system is adequately prepared and equipped to deal with the sound measurement according to the existing provisions of section 386, Subdivision 2 of the Vehicle and Traffic Law. However, when it is noted that the 45 arrests were made after checking 9569 vehicles, it would appear that further study and

evaluation is necessary to determine whether the present measurement of soundpressure levels is efficacious."
(Kirwan, William E., Superintendent, by Robert E. Sweeney, Jr., April 15, 1968.)
The author does not share the view that our enforcement and judicial system is adequately prepared and equipped to deal with sound measurement and related problems under this section. As a practical matter, antinoise and muffler violations are usually dismissed because of inadequate provision for enforcement measurement and proof in court.

28. See West's Annotated California Code, Sec. 23130; (Comprehensive Motor Vehicle Noise Statute).

29. Here is a listing of the antinoise laws, codes, and ordinances of the various states:
Ala. Title 36, Sec. 39 (muffler required—hereafter MR); Alaska—no stat.; Ariz.—Rev. stat. Sec. 28-944 as amended (1967 (MR); Ark.—Stat. 1947 Anno. Title 75, Sec. 725, (MR); Calif.—West's Anno. Code, Veh. Code Sec. 23130, Pen. Code Sec. 415 (crim. penalty for disturbing the peace specifically includes noise); Col.—Rev. Stat. 1963 13-5-105, (MR); Conn.-Gen. Stat. Anno., Sec. Anno., Sec. 14-80 (MR); Del.—Code, Sec. 561 (Liq. Comm. may suspend liquor license of establishment for noise), Sec. 4311 (MR); Dist. of Col.—Code Sec. 1-224 (Atty's. Comm. to adopt leg. prohib. loud noise); Fla.—Stat. Anno. Sec. 317-637 (MR); Ga.—Code Anno. Sec. 68-1717 (MR); Hawaii—Rev. Laws Sec. 267-1 (Nuisance defined to include making loud and troublesome noises at night), Sec. 311-24 (Unlawful to ride motor scooter with muffler designed to increase noise); Ida.—Code Sec. 49-835 (MR); Ill.—Smith-Herd Anno. Sec. 215 (MR) Chap. 95½; Ind.-State. Anno, 47-2230 (MR) 48-1407 (Cities authorized to adopted regulators to control noise); Io.—321.436 (MR) 368.7 (7) (Incorporated town may adopt reg. limiting noise etc.); Kan.—Stat. Anno. 8-5, 103 (MR), 82a-809 (Motor Boat); Ky.—Rev. Stat. 84.220, 85,180, 86.150 (Governing bodies of cities may generally adopt reg. to control noise), 189.140 (MR—not uniform language); La.—Rev. Stat. 32: 352-253 (MR may not modify exhaust system to increase noise); Maine-Rev. Stat. 29, Sec. 1362 (Shall not operate automobile in manner which would produce excess noise. MR); Md.—Anno. Code 66½, Sec. 294 (MR), Sec. 296 (Pen. misd.), 27, Sec. 124 (Disturbing the peace); Mass.—Gen. Laws 272, Sec. 44 (Disturbing the Peace), 272 Sec. 41 (Disturb. in public Library), 90 Sec. 16 (May not operate automobile so as to produce excessive noise) 111 Sec. 143 (Limitation on trade and employment found to be a nuisance); Mich.—Compiled Laws 257.707 (MR, other noise devices); Minn.—Stat. Anno. 360.075 (Limitation on the use of loudspeaker from airplane), Sec. 169.69 (MR); Miss.—Code Anno. Sec. 2088 (Crim. pen. for making noise with intent to disturb family), 2090.5 (Disturbance in public place), Sec. 8251 (MR); Mo.—Stat. Anno. Sec. 304.560 (MR), 562.240 (Disturbing the peace); Mont.—Rev. Code Sec. 32-21-145 (MR); Neb.—Rev. State. 1943 Sec. 39-777 (MR); Nev.—Rev. Stat. 486.120 (MR on power cycle, reason not given); N.Hamp.—Rev. Stat. Anno. 263.46 (MR); N.J.—39: 3-70 (MR), 39:4-78 (No person shall load veh. of iron or other unusual noise material which may strike together without providing for deafening) 40:48-1 (Governing body of municipality may adopt reg. to regulate ringing of bells, crying of auctioneers, etc.); N.M.—64-20-44 (MR); N.Y.—Nav. Law, Sec. 20-128 (MR), Veh. and Traffic, Sec. 375(31) (MR), Sec. 381 (Muffler on motorcycle); N.C.—Gen. Stat., Sec. 20-128 (MR); N. D.—Cent. Code, 39-11-29 (MR); Ohio—Rev. Code, Sec. 2923.41 (No person shall, after a request to desist, continue noise which disturbs peace), Rev. Code 4513.22 (muff. reg. but it has held that this is for exhaust and not noise. *State* v. *Cox,* 193 NE 2d 297); Okla.—Anno. Stat. 47 Sec. 12-402 (MR); O.—Rev. Stat. 483.448 (MR); Penn.—State Anno. 75 Sec. 828 (MR); R.I.—Gen. Laws 31-23-14 (MR); S. C.—Code Sec. 460601 (MR); S.D.—Code 44.0350 (MR); Tenn. -Code Anno. 59.902 (MR); Tex.—Vernon's Anno. 1.C Art. 796-797 (Limitation on use of horn, bell, etc. on motor vehicles), Art. 7975 (MR); Utah—Code Anno. 41-6-147 (MR); Ver.—Stat. Anno. Sec. 1097 (Prohib. against cut-off muffler, noise not mentioned); Va.—Sec. 461.(-301); Wash.—Rev. Code Anno. 9.76.010 (Limitation of noisy business on Sabbath), 46.37.390 (MR) W. Va.—Code Sec. 17c-15-34 (MR); Wis.-Stat. Anno. 347.39 (MR) Wy.—Stat. Anno. 31-205 (MR).

30. See Goldstein *supra* note 10 at p. 33.

31. Sec. 435-50 of the N.Y.C. Administrative Code states generally that "the creation of any unreasonably loud, disturbing city noise did not continue. Finally, in August of 1967, New York City again awakened to the noise problem. Neil H. Anderson, Executive Vice President of the New York Board of Trade, was appointed chairman of a committee directed to study the problem and produce.
". . . some noise rulings which will bring these developments (quieter trucks, tires, mufflers) into everyday use."

See statement by Neil H. Anderson before New York City Council during hearings on reorganization of the City Government, Local Law 280, Int. #261, ch. 56, as reported *Congressional Record* August 31, 1967, at page H 11529.

Hopefully, the New York City task force will produce hard results in the noise reduction and control field in addition to its study of the problem.

32. Robert Alex Baron, a private citizen who has demonstrated considerable interest in the noise abatement cause, recently told the Fourth International Congress on Noise Abatement at Baden Baden, Germany, in May 1966, that

". . . in one 26-year period, garbage collection moved up to first place in a list of the ten most disturbing noises in New York City."

The garbage is usually collected early in the morning (3-5 a.m.). The operation of the turnstile which pulverizes the refuse and jams it into the garbage truck, together with the clang from the metal garbage can and metal objects within it, combine to cause a substantial racket which rudely awakens many residents in apartments throughout the block.

New York City's acting Commissioner of Purchase recently joined forces with the Sanitation Commissioner to reverse the noisy trend of garbage collection by ordering 800 "quiet trucks to be used for sanitation purposes." (See N.Y. Times, August 18, 1967.)

33. Mr. Baron *supra* note 32 also stated that

". . . New Yorkers are assaulted each year by the noise of some 10,000 demolition and building projects, plus 80,000 street repair projects. New York City does little or nothing to abate construction noise. In common with most cities, it exempts daytime construction from any noise control and allows loopholes for night time construction. Construction noise, like most other sources, is often excused as a 'temporary nuissance,' even though it exists nearly every day and many nights, year after year."

34. The National Institute of Municipal Law Officers has set forth in a book by Charles S. Rhyne three "model ordinances," which would regulate and prohibit the following: (1) certain use of sound trucks; (2) certain uses of sound advertising from aircraft; and (3) unnecessary noise. This book—entitled "Municipal Control of Noise—Sound Trucks, etc."—together with annotations provided, makes an excellent reference source for cities in their exploration of ways to draft codes or improve their existing ones. It also speaks of the Constitutional right of freedom of speech and the validity of local noise control statutes.

35. Spater *supra* note 1 at p. 1374:

". . . the story of noise and the law is not one of the development of new principles to fit new noises, but the application of established principles to solve old problems in somewhat different forms."

36. Spater *supra* note 1 at p. 1378, and the following at pp. 1379, 80:

"Contrasting sharply with these situations requiring negligent design and operation, or inappropriate location, or material damage before an injunction can be obtained, there are numerous circumstances in which a relatively minor showing of annoyance will be deemed sufficient for the granting of relief. For example, if the defendant deliberately made the noise for the purpose of annoying his neighbor, the plaintiff can enjoin the continuance of the noise no matter how slight the annoyance. Similarly, continuous loud music used for advertising that is above the level of the other sounds in the neighborhood can be enjoined without much showing of economic loss or personal injury to the plaintiff.

"In addition, courts seem quite ready to grant equitable relief against noises resulting from the operation of what our Puritan consciences might think of as frivolous activities such as a carousel, a drive-in movie, an amusement park, a dance hall, or other places of entertainment. Here, apparently, is one area where the low utility of a defendant's conduct scores heavily against him and is commonly outweighed by the annoyance to his neighbor."

Control of Noise through Propaganda and Education

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Can propaganda and education be effective in community noise control? To date, the answer is a negative one. To see why and to learn how propaganda and education can be effective steps in noise control, we must inspect closely some examples in each category and see why they failed.

Propaganda against noise or for noise control has many facets with many levels.

For many years one of the most famous propaganda organizations was the now-defunct National Noise Abatement Council. It was supported by industrial firms interested in selling noise-control products, and by some organizations seeking means for noise abatement. It mailed a wide variety of materials, sponsored meetings, and gave awards to communities, organizations, and manufacturers each year for notable noise-abatement activities. The National Noise Abatement Council never achieved the prominence or effectiveness that the public outcry against noise should have warranted, and in 1961 it was disbanded.

Turning now to another high-powered propaganda organization, let us look at the National Air Transport Coordinating Committee. This group lasted less than 10 years. Its purpose was to process complaints about airport noise and to convince the public, civic officials, and legislators that the noise from aircraft near airports wasn't really that noisy. I have seen no official death notice of the organization but I can't remember reading about it or any appointments to its board or to the post of executive director for some years. Its job was to sell an unmarketable commodity to an already oversold public.

Another propaganda organization that has a similar unpalatable job is the National Aviation Noise Abatement Council. Its apparent task is similar to, but more extensive than, its predecessor's: Its members are still trying to convince the elected and appointed officials of our communities, our legislators, and an essentially nonflying public that the aircraft industry and airport operators are doing everything possible to make the neighborhood around the airport a quiet, pleasant place to live. They also seem bent on obtaining the privilege of self-regulation for noise; to date they have had success only in promoting some degree of self-regulation—certainly a negative result in terms of our objectives here today. Both the Airline Pilots Association and the Airport

Operators have withdrawn their support. Again, it appears from the outside that you cannot market aircraft noise by calling it perceived noise (PNdB), effective perceived noise (EPNdB), NNI, CNR, NEI, or NEF. Others who have participated in the effort to make the descriptors of the noise more palatable—this is a routine propaganda technique—are the Federal Aviation Administration and the Society of Automotive Engineers. This, by the way, is no criticism of either group. They have a difficult task on their hands. They either have to come up with quieter aircraft and quieter aircraft operations or sell the public on allowing the high-level noise (and I don't care what you name it) to stay at its present levels or, in some cases, to climb somewhat in time and duration. On the other side is the Citizens League Against Sonic Boom. So far, it has had little success in accomplishing its purpose, although it generates much publicity and is widely quoted. As I said, to date, propaganda has not worked.

Some other propaganda efforts have had modest success. Memphis, Tennessee has for many years been noted for its "quiet." It has received the National Noise Abatement Council Award many times. Basically, local officials mounted a campaign based on civic pride to take advantage of individual action; in general it worked. Similarly, an "anti-noise" campaign in New York in 1956 minimized hornblowing with the help of posters, signs, cartoons, and police fines. The campaign actually resulted in a diminution of noise from this source, which I believe is still observable today although not in midtown. These are two of the best examples that I can offer about successful propaganda and neither provided an effective long-term solution to the problem or is truly effective at this time.

As early as the late 1930s you could hear the announcer on some local radio stations, drifting in from the neighbor's radios, suggesting that now, at this late hour of the evening, the listener should turn down his radio volume in order to be a good citizen and good neighbor. But who ever bothered?

Another interesting propaganda method is, simply, to call noisy products quiet. Noisy as the products are, manufacturers are getting away with it. This applies particularly to room air conditioners in the 1960s. Many advertisements proclaim how quiet these units are. They refer to them as quiet, silent, noiseless when in fact they are just a few decibels quieter than the previous year's models. No one really believes any of this. Yet, as effective advertising, it does get the prospect into the store to see for himself; possibly, he will buy one even if it is not as quiet as the ad billed. This leads directly to my personal conclusion about straight propaganda: Today, nobody really believes it. The corollary was expressed to me by a resident of the Bronx as I measured noise of aircraft leaving LaGuardia Airport in the early 1950s. "Sure," he said, "I don't like the noise and the rattling windows, but you can't fight city hall." There is a corollary to this: Propaganda for public consumption cannot be effective unless there is visible activity to support it.

Another kind of propaganda, one with which I have been working for the past 20 years, is the dissemination of technical information about noise and its control. Through this avenue, those who are technically proficient in other areas can be made aware of the techniques for approaching noise-control problems and for determining needs for noise abatement and the methods used for noise control. I have served as editor of three publications, two of which are still in business. As to the demise of *Noise Control* magazine, it was not brought on, as some have indicated, by a lack of material but by a policy problem within the Acoustical Society of America, whose members and officers were divided over the Society's place in publishing such a magazine and over how much and for how long money would have to be committed to make the magazine self-supporting. Today, *Sound and Vibration* magazine is reaching one of the most deeply involved audiences whose members are in all branches of science, engineering, industry, and commerce.

Reader response to technical articles and editorials is quick and literate. Response to product and literature announcements and advertising is surprisingly large for a readership amounting to only a little over 12,000. It is still too early to say for sure but, as a medium for technical propaganda, *Sound and Vibration* may reverse the negative trend. One of my problems as editor has been the nontechnical writer. Every few months I receive letters from people who offer to research any subject and write an article of any assigned number of words; the closing line of their letters is always, "How much do you pay per page?" I don't believe that a public relations firm or a nontechnically trained, professional writer can convey the picture correctly.

Factual inaccuracy arising from ignorance may also be the problem in marketing truly effective quieting devices. As an example, the widespread lavish claims made for sound-isolating doors are often irresponsible in the face of results of laboratory tests done in accordance with the appropriate ASTM procedure.

Have we done any better using education to achieve a quieter world? The answer is a qualified "no." With all of the technical knowledge available within the field of acoustics (that Botsford has pointed out earlier in the Conference) only the smallest amount of useful information appears to be included in classroom or laboratory work. I am often appalled at the misinformation that is submitted to me, as an editor, from people in the academic world. They have not done their homework. I am sure that there are many reasons for this, but because I read course outlines, graduate theses, and other submitted papers I can only come to some negative conclusions:

1. There is a large amount of technical theoretical acoustics taught in graduate and postgraduate courses at leading institutions.
2. There are so many facets to the field of noise control that the field is unattractive. (How many mechanical or electrical graduates are acquainted with group psychology, psychological-test design and interpretation, physiology of the ear, architectural construction practices, mechanical damping, and nonparametric statistics?)
3. There is a beguiling simplicity in the apparent ease with which acoustical

measurements may be made using readily purchased equipment. In academic work the real problems of measurements and their apparent inconsistency do not arise. Thus even the trained college graduate is not really trained to face work outside the academic world, and his laboratory answers may be inapplicable outside of his or another laboratory. This, of course, is discouraging to anyone.

4. Noise control in industry is like quality control: The personnel are not usually greeted with delight by the production department. They are often viewed with suspicion as cost raisers and troublemakers. I ask you: What kind of satisfaction is there in that for the new graduates, especially when they can go into computer work or value engineering and show how to save money?

At this point you may well be asking, "Is there any hope for either propaganda or education as effective techniques for noise control?" The answer is an unqualified "yes." I believe that we must search for the motivating factors of mass psychology and, simultaneously, try to achieve major noise reductions that will lead to effective reductions in emotional stress. If people are willing to tolerate more noise because they want the noise source around, they will be even more responsive to a modest reduction in the noise level. This is a fact that the air transport industry has consistently overlooked. The Air Force, using effective propaganda techniques, has its "Sound of Safety" slogan and probably has a 15-dB margin of tolerance over commercial aircraft.

We must also apply the idea of motivation to manufacturers of noisemaking devices and users of noisy industrial machinery. Also, the public must abandon both the "You can't fight city hall" and the hysterical approaches and bring consistent written and telephone pressure to bear on elected and appointed representatives at all levels of government. Using an example from a different field: We have not done well in motivating safe driving, but we are getting people to use seatbelts. Who can help but be motivated by the propaganda used?

I believe that more educators should spend time in the industrial and commercial world, not as consultants, but as members of design or industrial laboratory staffs so that they can see the discrepancies between theory and practice, so that they can see the need for a broader approach to noise control, and so that they might learn at first hand the nature of the problems facing their students on graduation.

Two of the most effective means for education and interchange of ideas are through continuing education and national and regional symposia, yet no professional or industrial-commercial support appears to provide adequate financing for such ventures. Although there have been several courses in continuing education, such as those offered by the Center for Professional Advancement, Bolt, Beranek and Newman, the MIT Summer Program and Penn State, they are available to less than 300 people a year. The Annual

National Noise Abatement Symposium of the 1950s drew a large attendance and was a useful forum for interchange of technical information, but lack of support by the sponsoring organizations led to its quiet abandonment. A West Coast Noise Abatement Symposium lasted only four or five years.

Here is what I can suggest:

1. That the use of an educational clearing house could improve undergraduate and graduate education in this field.
2. That suitable publications, not dry, textbook-type material, should be available to schools interested in a noise-control course.
3. That continuing education programs be used effectively by industry.
4. That the National Noise Abatement Symposium be reestablished.
5. That mass media be used as a means of education, tying the formal educational process together with an effective public information program. (This would also serve to interest students in the noise-control field.)

In conclusion, it appears to be possible to reverse the trend toward polarization of the noisemaker versus the noisehater. To do this I believe that there must be a unification of national purpose to provide a goal and to generate motivation. There is no doubt that if the stressful and harmful effects of noise are to be eliminated it is going to cost money, and everyone—the public, industry, and commerce—will be called upon to pay.

However, effective public relations techniques can instill the motivational force, can develop an appropriate public attitude, and can obtain allocation of adequate funds.

Then with older colleagues, graduates of enlightened courses in the field of noise control will be able to achieve our noise-control goals and make this country a quieter, pleasanter, less stressful place in which to live, work, and enjoy the benefits of leisure time.

City Planning and Noise

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Introduction

Noise, by and large, has been an afterthought of city planning. This is regrettable, certainly, in view of the high aspirations of city planning to help achieve "the good life," which, according to Aristotle, men remain together in cities to live. It is all the more unfortunate because of the many opportunities for the alleviation or abatement of contemporary noise nuisances that the process of city planning has the potential to provide. It is time to re-examine the state of the art and priorities for urban noise control in the interest of more effective environmental planning.

The doctrine of American city planning has included concern for city noise ever since the City Beautiful Movement began. A 1911 textbook on Daniel Burnham's city plan for Chicago states:

> We recognize, for one thing, that city life is more intense and nerve-straining than life in the country. This means that our plan must aim to do away with unnecessary noises, smoke, dust, dirt, confusion . . . (Moody, 1911)

The Town-Planning Chart, drafted by the Fourth International Congress for Modern Architecture in 1933, declares the following:

> Buildings erected on heavily traveled streets and in the neighborhood of corner crossings are made undersirable as dwellings because of noise, dust, and noxious gases. (Sert, 1942)

The objective of urban noise control carries on through planning and into the origins of zoning. Zoning invokes the municipal police power to protect the public interest through regulation of the use of land and buildings. It is therefore one of the essential techniques available to cities to implement land use and development plans. Zoning proceeds on the principle that urban land may be divided into districts in which uses that tend to be compatible in their functional characteristics may be grouped so as to prevent or minimize conflicts among activities. Land uses thus are grouped or segregated in zoning districts according to their apparent compatibility, and regulated further as to function and form.

Noise has been recognized as one aspect of potential incompatibility, or a source of potential nuisance, among land uses since the earliest years of comprehensive zoning. In 1926 the U.S. Supreme Court took note of zoning as a means to "decrease noise and other conditions which produce nervous disorders."[1] In 1954, in a case of landmark importance for city planning and urban renewal, the Court again went to some length in acknowledging the protection of "public safety, public health, morality, peace and quiet, law and order" as "traditional applications" of the police power.[2]

Noise control through zoning and planning attained a plateau of refinement in the 1950s with the emergence of a concept of performance standards for industrial zoning. The publication in 1951 of a guide to such performance standards by the American Society of Planning Officials (O'Harrow, 1951) resulted in the introduction of reasonably precise and scientific ways of measuring noise emission. Such standards were needed to provide a workable basis for administration and enforcement of zoning controls intended to achieve and protect compatibility among the diverse uses of land in the American city.

The zoning regulations for the District of Columbia reflect the influence of this attempt to quantify and regulate noise emissions. The regulations for General Industrial Districts prescribe, in part, this:

> Maximum sound pressure levels [of sound inherently and recurrently generated by the use of land] shall not exceed those set forth in the following table, except that where a General Industrial District abuts a Residence, Special Purpose, or Commercial District, maximum sound pressure levels along the boundary separating the General Industrial District from such Districts shall not exceed the standards set forth [for the abutting district]:

Octave band in cycles per second	Maximum sound pressure level in decibels (0.0002 dynes per square centimeter)
0-74	79
75-149	74
150-299	66
300-599	59
600-1199	53
1200-2399	47
2400-4800	41
Above 4800	39

The regulations also prescribe that sound levels shall be measured with a sound level meter and associated octave-band filter manufactured according to ASA standards, and the following:

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[1] *Village of Euclid v. Ambler Realty Co.,* 272 U.S. 365 (1926).

[2] *Berman v. Parker,* 348 U.S. 26 (1954).

> objectionable sounds of an intermittent nature shall be controlled so as not to become a nuisance to adjacent uses.[3]

Such regulations, perhaps difficult to apply in creative civic design, are nonetheless important in preserving the integrity of land use plans developed with the practical intention of minimizing adverse noise exposure.

The police power and common law of nuisance now provide many precedents for abating or regulating noise at the political level of the municipality. Maximum noise emission limits have been incorporated in zoning controls for land use in many American cities. Chicago, Illinois and Warren, Michigan are typical of large and smaller cities, in addition to Washington, D.C., which have prescribed maximum noise levels for permitted land uses. Coral Gables, Florida, where limits for even home air-conditioner noise are in effect, claims title as the quietest American city, as does Memphis, Tennessee, on a larger but not louder scale. In all such cities, people disturbed by loud noises from local sources can appeal to local officials and courts for relief.

Metronoise

But maintaining the public peace and quiet in whole urban areas is becoming more and more difficult, even as the adoption of local noise control ordinances spreads. This is because the problem is becoming metropolitan, rather than local, in scale. Today, the most serious noise intrusions in the urban environment are made by aircraft, highway traffic, and other transport systems that operate beyond the purview of conventional local controls.

The futility of attempts to control noise from nonlocal sources by local ordinance is underscored by a recent judicial decision in the state of New York. The town of Hempstead, on Long Island, sought to impose noise limits on aircraft flying low over the community for landing and takeoffs at John F. Kennedy International Airport. A Federal judge, however, while recognizing the distractions and discomforts caused by aircraft noise for local residents, held that the "total social interest" of the metropolitan community served by operations at this airport outweighed the disadvantages to Hempstead residents. Accordingly, the local ordinance was judged unenforceable because it would restrict airport use and infringe on federal control of airline commerce.[4]

The public is beginning to discover that locally-based noise controls are generally not effective against noise from overflying planes and high-speed interstate roads. Local havens of quiet in parks and homes are being invaded by more noise every day. It has been suggested that city noise in the United States is increasing at the rate of 1 dB every year.[5] Against an increasingly pervasive background of aircraft engine and expressway noise, every intrusion

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[3] District of Columbia Zoning Regulations, 1958 ed., pp. 36-38.

[4] *American Airlines et al., Port of New York Authority et al.,* v. *Hempstead,* 10 CCH Aviation 17, 337, (1967).

[5] *Noise Control,* July 1961, p. 39.

by an occasional ambulance, lawnmower, or pneumatic drill is now felt more acutely by more people in urban communities. As a result, city noise has generated its own critical mass of controversy and a public demand for control.

But it is at the metropolitan level of contemporary urban planning that noise control and planning for noise exposure suffer serious retardation.

The metropolitan scale of environmental noise must be understood in terms of the vast areas that objectionable noise can affect as well as in terms of the immunity of much noise to traditional forms of localized control or abatement. In order to provide a better factual basis for understanding the scale of the environmental problem of aircraft noise, to define airport and related land-use-planning parameters, and to assess the cost of alternative measures for providing some degree of relief, the Department of Housing and Urban Development has studied present and projected land-use patterns in the environs of three of the most noise-troubled airports in the U.S.—the New York JFK, Chicago O'Hare, and Los Angeles International Airports. The areas studied for each airport were defined by the limits of zones of high noise exposure derived by contractors to the Federal Aviation Administration from projections of aircraft operations at the three airports through 1975, using the Noise Exposure Forecast concept developed by Bishop and Horonjeff (1967).

It was determined, on the basis of projections of land use, population growth, and aircraft operations, that by 1975 an area of approximately 36 square miles surrounding JFK Airport and including 373,500 residents would be exposed to aircraft noise of 40 NEF or greater. This level of noise exposure corresponds approximately to a Composite Noise Rating (CNR) of 115. Earlier experience with communities exposed to such noise levels indicates that residential communities may respond vigorously to such noise and in some cases seek relief through concerted group action (Bolt, Beranek, and Newman, Inc., 1964). For the same airport environs, NEF values of 30, corresponding approximately to CNR 100, were projected for an area of about 121 square miles with a resident population expected to exceed 1,700,000 by 1975. The same area already includes at least 112 schools, 37 public parks, and 12 hospitals, all patently noise-sensitive facilities. Similar, although somewhat less severe, noise exposure situations were indicated by projections of aircraft noise and urban development factors for the environs of Chicago O'Hare and Los Angeles International Airports.

The magnitude of these figures will illustrate the scale of the metropolitan aircraft noise exposure problem. Such figures may also suggest why the problem of transcending aircraft noise is not being dealt with in local or metropolitan urban planning. But it will be helpful first to consider who actually "plans noise" for cities.

Who Plans Noise for Cities?

Many interests and influences affect the evolution of the city in plan, as well as the city in fact. The city plan, especially on the metropolitan scale, provides for most cities a somewhat ephemeral framework of policy guidelines and recommended trends for development, sustained primarily by the power of suggestion. Many major development decisions involving metropolitan noise are made and carried out by agencies and interests who have had only the most casual, perfunctory, or belated relationship to any process of metropolitan or city planning.

Airport Noise

Airport operators and owners, whether in civil aviation or military, public or private by charter, have been doing most of the nation's noise exposure and noise abatement planning. They have had to do this planning mainly on their own. They are the uneasy heirs to the most acute concentrations of a large and very loud legacy of aircraft noise generated by the products of industries and technologies that they do not control. For the most part, they occupy facilities that are fixed in location, undersized, and relatively vulnerable to encroachment by development that may well be incompatible with the noise that their airports make. They must, therefore, plan for noise control and abatement in order to survive.

For primarily historical reasons, major airports have been evolving under the pressures of increased aviation independent of the planning agencies having a comprehensive range of concerns for development in major metropolitan areas. The aviation industry and its demands on airports have been evolving at more rapid rates than the political and governmental machinery that fosters city and metropolitan planning. Only since the advent of the jet age have most airport authorities and planning agencies found an urgent common cause in the problem of areawide noise abatement.

Common cause notwithstanding, airport authorities are charged primarily with the business of running and developing airports apace with aviation growth, whereas planning agencies are inclined to regard airport development as but one among several classes of metropolitan problems—including all forms of transportation, housing, urban renewal, open space and recreation, water and air pollution, and the elimination of poverty and crime—that require intensive consideration. To make matters worse, few of the 200-odd metropolitan planning agencies that exist today have programs sufficiently advanced or staff technically trained to render much assistance to airports in dealing with community noise exposure problems.

In planning for their own expanded operations, such as increased volumes of passenger or air cargo traffic, airports are, in effect, planning some of the major patterns of metropolitan noise distribution. These patterns may be altered, or their noise intensified, by the airport's choice of alternative runway configurations; policies for preferential runway use; aircraft ground-handling procedures, including maintenance operations; and, of course, by the airport's flight path controls and regulations on hours of operation. Many of these parameters of aircraft noise exposure are subject also to influence or approval by the Federal Aviation Administration, but the initiative to make or modify civil airport plans rests almost entirely with local airport authorities.

Airport development plans and proposals seem to have been notably free from local debate on the question of noise effects that such plans might produce in neighboring communities. In many areas, it appears that localities troubled by increasing noise intrusion from approaching or departing planes have learned the severity of their actual noise exposure only after the fact of airport development and too late to obtain relief without appearing to obstruct regional progress or prosperity. Thus deprived of meaningful alternatives, the airport's neighbors are more likely to seek their relief through suits for injunction or compensation than through some rational process of facility planning that considers community noise exposure in advance.

Highway Noise

Urban arterial highways, also prominent, if not predominant, producers of urban environmental noise (Wilson, 1963), provide another case in point. Highways are an obviously important concern of comprehensive urban planning. Until 1962, however, Federally assisted urban highway planning and construction, as statutory responsibilities of the states, were notably beyond the political or practical purview of agencies created to perform city or metropolitan planning functions in the purely local public interest. The Federal-Aid Highway Act of 1962 changed this relationship by establishing a requirement that, after 1965, Federal-aid highway program funds could be used for projects in urban areas of more than 50,000 population only if such projects were related to an established

> comprehensive transportation planning process for the urban area as a whole, actively being carried on by cooperative efforts between the States and local communities.[6]

Implementation of this provision was not accomplished until 1965, however, and by that time many hundreds of miles of high-noise highways in cities had been built or planned to the point of total commitment by state highway departments mindful mainly of geometric design, right-of-way cost, and road-user demand criteria. There is relatively little evidence that state-level agencies have actually taken account of noise effects of the new expressway systems that they have planned and built in urban areas, either in relation to individual noise exposure problems in the route selection process, or in relation to the ambient noise levels of the urban area as a whole. Thus, in pursuing their separate paths to solve other city problems, city planners and highway planners alike have done little to restrain the growth of highway noise as an adverse environmental factor.

This is not to say that not much is known about highway noise per se. There has been extensive research on problems connected with noise generated by engines, tires, and mufflers of highway vehicles. But all of this basic research is only a small part of the calculus of community noise control. It is also primarily

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[6] Federal-Aid Highway Act of 1962, Section 9.

retrospective in nature and provides information at a grain too fine for translation into the city planning process of preparing for urban development The fact remains that there have been very few occasions in which knowledge of projectable highway noise has been used as a factor in planning highway locations, giving due regard for the environmental values of the communities through which the highways must pass.

Encouraging attempts have been made to apply highway noise considerations to the actual highway planning process in West Orange, New Jersey (Goodfriend and Associates, 1963), and in a now celebrated case of highway-community conflict involving the historic French Quarter in New Orleans. The New Orleans experience is the more recent, and it illustrates the afterthought application of noise studies to a nationally controversial highway location and design problem. Scientific consideration was given to the predictable noise effects of the highway on the historic French Quarter, but not until nearly two years after the highway route selection was a fait accompli.

The short segment of interstate expressway proposed for the New Orleans riverfront helped to bring noise into focus as a mutual concern of the State Highway Department and local planning interests. The expressway proposal by the State Highway Department generated substantial controversy in the city and elsewhere in the nation, because the alignment bordered historic Jackson Square. This raised, in addition to esthetic problems, the prospect of introducing a major new noise source as a potential blighting influence in an area already troubled at times by the din of heavy commercial and industrial traffic.

Arguments advanced by the highway opponents concerning the probable impact of highway noise were made up mainly of conjecture, strongly supported by emotion, and were rebutted generally by highway officials with stony silence or analogies of questionable value. At that time, the Department of Housing and Urban Development was providing assistance to the city for a study of historic environmental and architectural qualities in the area. The Department therefore sponsored a specific study of the noise and other environmental effects of the proposed expressway, in order to establish the basis needed for a more rational choice of highway design alternatives in relation to other preservation and development objectives for the surrounding historic area. State highway authorities cooperated with HUD, the Bureau of Public Roads, and local planning interests, and postponed final design decisions on the expressway until completion of the environmental effects study and agreed to consider its recommendations for noise control.

The study of noise effects (City of New Orleans, 1966) included tape recordings of actual traffic noise at seven strategic positions in the historic area. Recordings were made in the late evening, early morning, midday, and at the late afternoon traffic peak. Traffic characteristics were analyzed to account for afternoon peak hour truck movements involving rapid acceleration and high noise peaks (sometimes in excess of 92 dBA) as well as inflated midday noise levels influenced by numerous sightseeing buses parked with motors and air conditioners left running. Projections of noise levels in the historic area were made by relating results of actual noise readings from comparable traffic conditions, including vehicle mix and highway profile, in Boston to noise levels recorded in the New Orleans area that would be exposed. Results indicated that after construction of the proposed elevated expressway, Speech Interference Levels (SIL) in one strategic location might be increased to 63 dB, which would require uncomfortably higher voice levels to achieve the same degree of intelligibility that present noise conditions permit. Study results also indicated that conversation would be interruped by speech interference levels about 68 dB six times more often than before. Other results suggested the need for special noise-reducing building construction in areas bordering historic Jackson Square, in order to meet the residential requirements.

The original design of the expressway may well be changed, in part because its costs in terms of environmental noise degradation and human discomfort have been quantified and found to be too high. Alternative designs for the expressway, including both grade-level (levee-top) and depressed alignments, are being studied. The noise potential for each will be a factor in the design evaluation. It is still possible that a noisy road may one day run along the Vieux Carre, but not because the local planning was silent or superficial on the subject of unwanted sound.

Other Transport System Noise

Other prime offenders of the public peace and quiet in metropolitan areas are railroads, rapid transit, and helicopter transport systems. Railroads are largely a legacy for metropolitan planning. Historically, they were planned when noise was viewed as the public price of progress, and have been relatively immune against noise complaints. They no longer present demands for new lines through peaceful cities and towns. Railroad noise, even without the cinders and steam of an earlier era, has its effects in the inner cities; miles of right-of-way lined by persistent slums are ample evidence that the market rejects the railroad environment for all but the poorest of housing. Even with redevelopment funds and powers, residual railroad lines pose formidable problems in planning the reuse of adjacent land, because the original problem of noise control often remains.

Rapid rail transit systems until recent years have not been too concerned with noise control and abatement, neither for riders nor for neighbors of above-ground lines. The disruptive noise of the overhead "el" is legendary from Charlestown, Massachusetts, to Brookyln, New York, and Chicago's Loop. Transit management has learned that noisy rapid-rail operations can exact heavy penalties in ridership and public acceptance of system extensions needed to tap new revenues and to improve service, however, and there is evidence that new systems under development will, by design, have far less noise impact in cities. The San Francisco Bay Area Rapid Transit System has made a demonstration study to evaluate the possibility of reduction of noise and vibration associated with the operation of rail rapid transit facilties (Parsons et al., 1968). The study identified sources of noise, evaluated means of noise control and potentials for reduction, and recommended a continuous program of noise monitoring measurements and remedial actions. Test experience with new transit systems, such as the Westinghouse Skybus, which uses small, automated rubber-tired trains moving on lightweight overhead beams, indicates that quiet systems can be efficient too. It seems likely that transit planners can face the future with the pleasant prospect of offering comparative silence as a competitive advantage among systems that can serve people within the framework of the city plan.

Helicopters, obviously able to deliver annoying noise anywhere in a metropolitan area, already are under skeptical scrutiny as an urban transport mode by a public made nervous by too much noise. Opposition to noise has resulted in the imposition of strict controls on flight paths to and from New York's Pan Am rooftop terminal, and has stymied sympathetic planners' attempts to install even a temporary helipad in Southwest Washington, D.C. Until quieter V/STOL aircraft are developed, it is doubtful that these versatile, but extremely noisy, machines will be tolerated in large numbers in most metropolitan areas.

It is too soon to say who is planning for V/STOL aircraft noise distribution. City planning has been concerned primarily with terminal locations and interconnecting systems. V/STOL aircraft noise levels, however, already provide incentives for rapid development of new concepts for terminal placement and noise-corridor planning on the metropolitan scale.

Considering just the array of independent actors involved in planning for the distribution of urban noise from major sources, it is no wonder that the din in cities is increasing. There is also a paucity of information about how to plan effectively for environmental noise control and about the effects of contemporary episodic and ambient noise levels on people. Essentially all of the current literature in the practice of urban planning is silent on the subject of noise. A few texts make polite passing reference to the growing presence of noise in cities, but fall back on citations of typical zoning and nuisance controls long since outrun by the noise of newer technology. Accordingly, city planners and cities themselves have at best a limited perspective on the problem of environmental noise and means to respond to public pleas for greater peace and quiet.

Failure to apply principles of urban noise control threatens to make a mockery of the concept of compatible land usage on the metropolitan scale. For example:

1. Even while the San Francisco airport was under suit for $3.4 million by residents of the city of Millbrae for noise damages, the city continued to grant building permits for additional residential units in the noise-affected area (Wood and Lambke, 1967).
2. In New York City, despite FAA warnings that building sites are certain to be exposed frequently to noise levels well over 100 dB in the immediate

future, and are even now problematic, the city has granted zoning changes to permit the construction of high-rise apartment developments(housing up to 6000 families in one project) located in well-known and practically unchangeable flight paths.

3. In Boston, state and other airport authorities, faced with a lack of buildable land for expansion to construct a new jet runway aimed directly at several built-up communities; the projected zone of 115 CNR for the proposed runway overspreads an area that already includes at least 8000 people, four public schools, and part of the Chelsea Naval Hospital.
4. Congress has directed the Secretary of Housing and Urban Development to

> undertake a study to determine feasible methods of reducing the economic loss and hardship suffered by homeowners as the result of the depreciation in the value of their properties following construction of airports in the vicinity of their homes, including a study of insulating such homes from the noise of aricraft.[7]

These illustrations also reflect the fact that no adequate method for allocating the cost of aircraft noise abatement in the metropolitan community has been found. Such cases arise from a less than optimum mix of market forces, governmental controls, public expectations, and technical information, all of which city planning tries to take into account. Noise has become a factor in all of these aspects of planning.

Because of the scope of metropolitan noise exposure problems, and variations in patterns of development among metropolitan areas, it is necessary to recognize two approaches to noise abatement through city planning. These approaches are through remedial or preventive planning. Each approach offers different prospects for success, depending on the character and intensity of development near the noise source, such as the highway or airport. One type of remedial action, achieving or restoring compatibility among land uses by converting developed land to other use, is a seriously limited technique. Areas already exposed or committed to very high noise levels are very large, and the cost of extensive property conversion would be astronomical. Prospects for preventive planning to avoid or minimize future noise problems are much better, however, and they suggest certain steps that might be taken.

Proposals for Planning To Control Metropolitan Noise

City planning for noise control needs to regain perspective on the problem. This will require concentrating on the priority areas of noise at the metropolitan scale, and primarily on highway and aircraft noise. All proposals proceed from the premise that knowledge of noise exposure in advance of the "community problem" is the key to planning and both preventive and remedial actions to deal with problems of city noise. There is the further premise that

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[7] Housing and Urban Development Act of 1965, Sec. 1113.

available means for predicting noise are rarely being used. It is time to join noise generation technology with the softer science of land use planning in the context of the metropolitan area.

First, the urban expressway proposals should be subjected to systematic studies of their noise effects. There is little dispute that less noise is better than more for most people in their homes, parks, and schools even though individual tolerances may vary widely. If this is so, there is no reason why a right-of-way "footprint of sound" should not be plotted and analyzed to determine the noise exposure potential for urban expressway and arterial street systems as part of the urban planning process. Methods of predicting highway noise in advance on the basis of predicted traffic volumes and rates in relation to community response are reported (Goodfriend, 1967). There remain to be built 2500 miles of the nation's Interstate Highway system in metropolitan areas, and innumerable arterial streets to be improved. These projects present opportunities to achieve more peace and quiet through urban highway planning and they should not be allowed to pass.

Second, airport development and operational plans should be reviewed jointly by airport authorities and surrounding communities with full regard for projected aircraft noise exposure conditions. Open consideration of projected community noise exposure implications of airport development plans by responsible officials is essential to protect the interests of the general public and airports through compatible land use planning. Aircraft noise projection techniques suitable for many general planning purposes are available in the CNR and emerging NEF concepts (Federal Aviation Agency, 1964). Projected contours for CNR values are already in use by the Department of Housing and Urban Development (1965) to guide determinations of the acceptability of properties for mortgage insurance in zones of high noise exposure near airports. Similar guidelines can and should be applied by local government agencies involved in planning land use and airport development.

Third, insulating homes and schools against aircraft and other exterior noise intrusions must be recognized as a compromise method of achieving compatibility between noise-sensitive and noise-generating land uses, such as airports and urban expressways, in both preventive and remedial planning situations. Preliminary guidance for insulating existing houses with respect to aircraft noise has been published by the Department of Housing and Urban Development (1966). Field testing of these techniques in areas of severe aircraft noise is now underway to determine practical costs and benefits. Other experience with nonresidential structures, including schools, offices, and motels, indicates that noise installation can make the difference between land use compatibility and potential nuisance or hardship conditions in extremely noisy areas. Further research in techniques is needed, especially to determine the effects of noise on people, but land use and transport system planning now should consider costs of home insulation, as well as the social costs of community exposure, as trade-off factors in analyzing costs of noise-generating system development proposals.

Fourth, development plans for airports impacted by urban development should be subjected to systems analysis to insure maximum benefit of many techniques for minimizing noise exposure problems. Such analyses are essential to buttress the benefits that may be gained by the single-purpose approach to manipulating land use patterns in fixed areas. Systems analyses of airport problems in the pursuit of compatibility for the airport with its environs must include considerations of flight paths, ground-handling procedures for aircraft, maintenance runups, airport operating hours, and, of course, the effects of alternative runway configurations on the metropolitan area.

The trend in airport development planning has been to seek ever-larger airport areas to achieve compatibility by imposing distance to attenuate noise. This trend is evident in the plans for the Dallas-Fort Worth International Airport as a 20,000-acre facility; Dulles Airport, serving Washington, with nearly 10,000 acres, was previously the nation's largest by a substantial margin. Obviously, few cities and metropolitan areas can hope to accommodate many airports of such gargantuan size. Neither can they afford to abandon most airports already established in built-up urban areas. The perspective of the city and metropolitan plan should guide the development of airport systems in either situation.

Machinery now exists in many metropolitan areas for applying more enlightened planning. Pursuant to Section 204 of the Demonstration Cities and Metropolitan Development Act of 1966, all applications for Federal assistance for many projects of metropolitan scale, including highways, airports, mass transportation facilities, open-space acquisition, and land conservation, must be submitted to a metropolitan or regional agency for review. Such agencies are now in existence in more than 200 metropolitan areas, and several are experienced in applying noise projection technology in the development of urban planning policy. Metropolitan development plans in Atlanta, particularly, reflect open consideration of airport needs and noise exposure in urban land use planning (Atlanta Regional Metropolitan Planning Commissions, 1966).

Federal law authorizes the Department of Housing and Urban Development to make grants

> in order to assist State and local governments in solving planning problems resulting from the increasing concentration of population in metropolitan and other urban areas.[8]

One of these problems is noise. In an era of rapidly rising public concern about environmental pollution, including noise specifically, any planning that ignores the noise effects of urban development decisions is anachronistic. City planning must be brought to bear to abate and control the generation of unwanted sound in our cities. The men who came to the city to live the good life of which Aristotle spoke need peace and quiet in which to consider and deal with the urban condition.

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[8] Housing Act of 1954, Section 701(a).

References

ATLANTA REGION METROPOLITAN PLANNING COMMISSION, *Atlanta Metropolitan Region Comprehensive Plan*: Airports, 1966.

BISHOP, D. E., and HORONJEFF, R. D., *Technical Report: 1965, 1970, and 1975 Noise Exposure Forecast Areas for John F. Kennedy, O'Hare, and Los Angeles International Airports.* Report submitted by Bolt, Beranek, and Newman, Inc., to the Department of Transportation, FAA, Washington, D.C. (1967).

BOLT BERANEK and NEWMAN INC., *Land Use Planning Relating to Aircraft Noise.* Technical report submitted to the U. S. Air Force and the FAA, Washington, D.C. (1964), p. 12.

CITY OF NEW ORLEANS, *An Evaluation of the Effects of the Proposed Riverfront Expressway on the Vieux Carre, New Orleans, Louisiana.* Technical report prepared as an extension of the Vieux Carre Historic Preservation Demonstration Grant Study by Marcou, O'Leary and Associates Wash., D.C.; Hammer Greene, Siler Associates, Wash., D. C.; Bolt, Beranek and Newman, Inc., Cambridge, Mass.; and Paul C. Box, Skokie, Ill. (November 1966).

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, FEDERAL HOUSING ADMINISTRATION, *A Study—Insulating Houses From Aircraft Noise.* Technical report by Bolt, Beranek, and Newman, Inc., Washington, D.C. (November 1966).

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT, FEDERAL HOUSING ADMINISTRATION, Underwriting Letter No. 1989, Washington, D. C. (April 16, 1965).

FEDERAL AVIATION AGENCY, *Land Use Planning With Respect to Aircraft Noise.* AFM 86-5, TM 5-365, Navy Docks P-98. Joint Manual of the U.S. Departments of the Air Force, Army, Navy. Technical report by Bolt, Beranek, and Newman, Inc. (October 1964).

GOODFRIEND, L. S., Control of highway noise. *Sound and Vibr.* (June 1967), p. 18.

GOODFRIEND, L. S., AND ASSOCIATES, *Preliminary Survey of Predicted Changes in Neighborhood Noise in West Orange, New Jersey, From a Proposed East-West Freeway* (1963).

MOODY, W. D., *Wacker's Manual of the Plan of Chicago,* Chicago (1911), pp. 62-63.

O'HARROW, D., Performance standards in industrial zoning. In *Planning 1951.* Chicago: American Society of Planning Officials (1951), p. 42.

PARSONS, BRINCKERHOFF, TUDOR, and BECHTEL, *Acoustics Studies, Technical Report No. 8.* San Francisco Bay Area Rapid Transit District (1968).

SERT, J. L., *Can Our Cities Survive?* Cambridge, Mass.: Harvard University Press (1942), p. 48.

WILSON, A. (ED)., *Noise,* London: Her Majesty's Stationers (July 1963), Chapter IV.

WOOD, S. E., and LAMBKE, D., *The Federal Threats to the California Landscape.* Sacramento (1967), p. 35.

Summary

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There is a growing conviction voiced again that Federal regulation must furnish the guidelines for action in noise control throughout the country. The motivation for this kind of action will probably be mainly twofold: (1) economic, and (2) major hazards.

Now, let's look at two major sources and see how these two motivating factors apply. First, truck noise. Dave Apps stated that there is no technical reason why we cannot control truck noise. Standards are available; mufflers can control engine noise; and proper tire tread design can control tire whine. The truck manufacturers already have adopted the voluntary limit, so what is the problem? In this case the problem resides with the truck operators. If you will watch trucks you will find that many of them are still running on the highways with no mufflers whatever. Furthermore, some operators still take crowbars and knock out the insides of mufflers, absolutely convinced that there is a penalty for operating with a muffler, in spite of the fact that this is not necessarily true.

Truck noise can be hazardous. Figure 1 shows the sound level inside the cab; it plots in the old-fashioned way, with octave-band levels, the sound spectrum inside the cab, to which the operator of the truck is subjected. You will notice that the spectrum in the cab is greater than any reasonable damage risk criterion; this means that there must be a great number of truck operators who have industrial, noise-conditioned hearing loss.

Many very severe accidents have been caused by excessive truck noise inside the cab.

Figure 1 shows the course of the sound level developed by a typical emergency or ambulance siren as the sound approaches the rear of a truck and passes. There is actually a period of only three seconds during that passage when the tuck driver can possibly hear the siren and then he may not be able to distinguish from siren-like noises coming from his own truck. Actual tests, presentating this combined signal to listeners, show that unless listeners are told exactly what to listen for they will not hear it. I submit that the history of truck accidents attributable to noise is terrible evidence of the need for control. This control which of course, would help the drivers, would also help the community.

These then are two major reasons why noise control is essential in an industry where it is indeed technically and immediately possible.

Figure 2 indicates that the diesel truck is the foremost major noise polluter in our country today. Its noise affects the millions of people who live along the thousands of miles of urban and suburban freeways and highways. Our measurements show that, in most cases, the diesel trucks are, in some bands, 20 dB higher in noise level than typical automobile traffic. This is a major difference, and an unnecessary one.

This figure illustrates a simple step that can be taken by residents who live beside highways and freeways: erect simple, fence barriers between their property and the highway; these will give very reasonable noise reductions. Figure 2 shows the reduction in the noise spectrum for automobiles in the lower curves, and for trucks in the upper curves, when the barrier is erected. It's a significant improvement by a simple measure.

Let us turn now to aircraft noise. Representatives of the engine manufacturers tell us that progress is on the way. Here is an example of noise control riding the back of economic motivation. It just happens, fortunately, that the road to noise control using the fan-jet principle also results in much greater takeoff thrust and cruising fuel economy. Good. Again, I think we must all reluctantly admit that Federal regulation, in the form of performance specification, is going to be the only way to assure the achievement of noise reduction.

Nothing has been said in this conference about the prospective engine noise from the proposed supersonic transport (SST). This prospect is a terrifying one. If this plane is to come into use it is very possible that it will have to meet a reasonable noise criterion: a launching vehicle may be necessary if it is to use existing airports. Unless we have strong regulation, I doubt very much that the

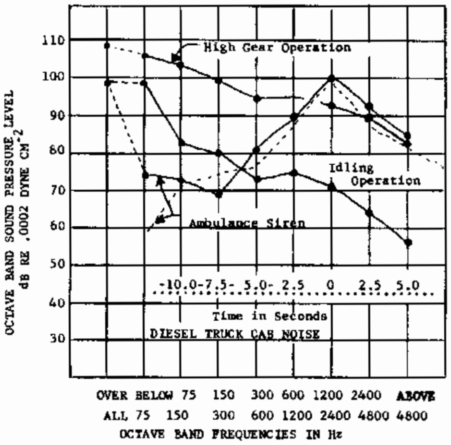

FIGURE 1. Sound level inside truck cab in high-gear operation and when idling and the course of sound level of an ambulance or emergency siren that approaches and passes the truck.

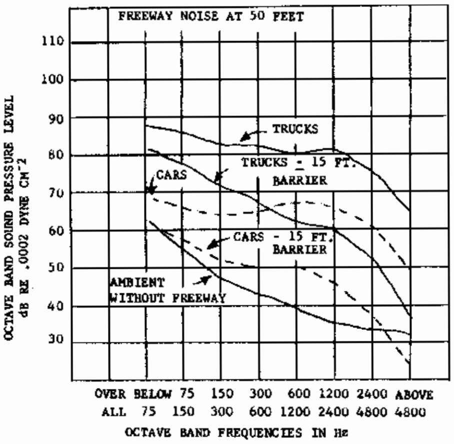

FIGURE 2. Noise level of diesel trucks compared with cars on a freeway heard at distance of 50 feet.

noise from this plane will be tolerable. Recall, for example, the days during the development of jet aircraft before they were introduced for public use. Management was very reluctant to do or even consider anything about noise. They wishfully counted on public tolerance, making and using propaganda. What better example of their hopeful propaganda is there than the name, Whisper Jet, on today's aircraft? The manufacturers and management were forced to action too late, about two years before the planes were introduced; then it was too late to take effective steps.

A major planner for an airport, a commissioner, as a matter of fact, was asked, "What is the prospect of public noise tolerance for this new airport plan that you are proposing?" And do you know what his answer was? He said, "They'll take it; they always have." History over the last ten years shows how tragically and callously blind that remark was. As a result we have on our hands one of the worst airport conditions in the country. This same blindness affected the architects for the airport; they, too, refused to listen to the warnings.

What we do need is effective team effort in this country so that noise control will be taken into account in advance and those who can contribute to noise control will have a voice. I do not believe we can wait for the aircraft manufacturers to solve all of the aircraft noise problem; it is too difficult and likely will take too long. History has never provided a decrease in noise; economic utilization has always more than used up any potential improvement provided by science and engineering. No, city planning and architectural ingenuity must do all they can—now.

I offer an example. It has been shown by reliable acoustical model studies that multiple dwellings may be designed and made in the form of noise barriers. Figure 3 illustrates this principle. The buildings nearest the sides of the airport runways are designed with sound resistng walls (including windows). They shield the intermediate access areas (canyons) to the next buildings; successively, each building barrier shields the ones beyond. The potential for noise control is very great—about 15 perceived noise decibels (PNdb). This control would permit continued residential occupancy—where it apparently wants to be—with an increase in land value and utilization approximately thirty-fold, compared to single dwellings! Instead, what we constantly have on our hands is property devaluation and interference with sleep.

What are the barriers to action? Public apathy is certainly one. And let us be fair about it, noise—perhaps relatively at least—must take a back seat to the importance of crime, delinquency, race problems, and war, surely.

One of the major factors standing in the way of action is diffuse authority. For example, the local government finds itself helpless to deal with truck noise. It is told that this problem is regulated by the state; the state says it is an interstate problem and can only be regulated by the Federal Government. We need decisions by legislature about where authority lies—to be sure that actions are sponsored by the proper authorities.

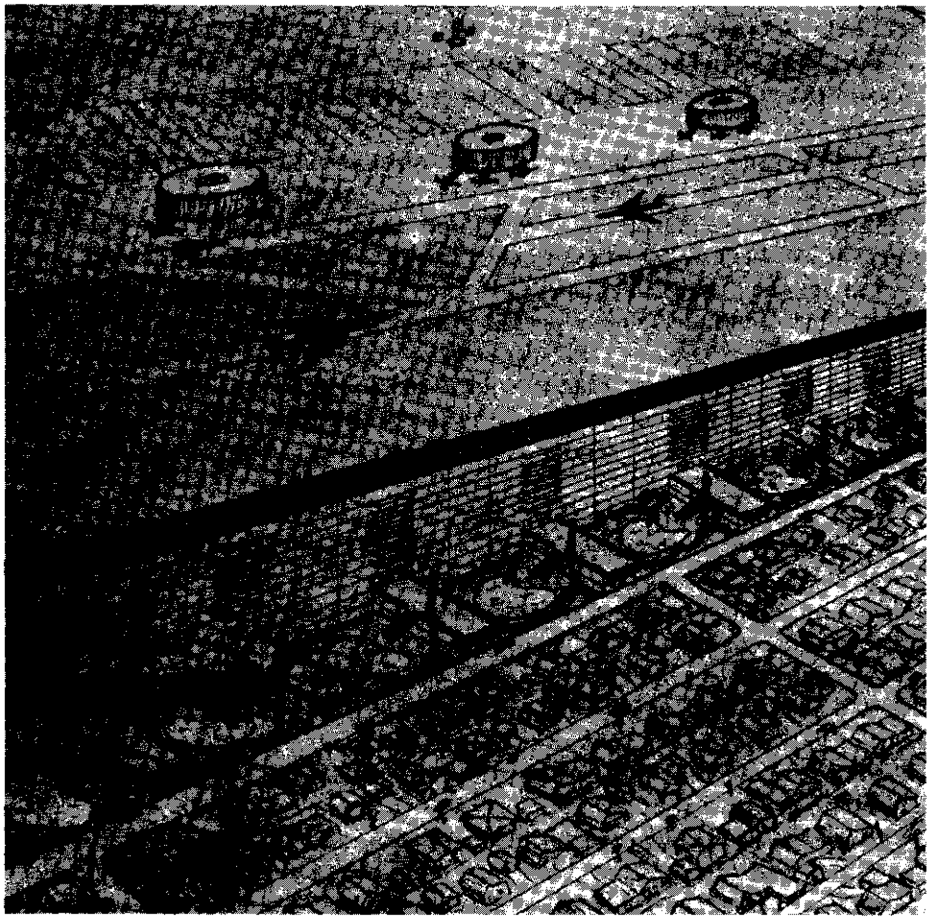

FIGURE 3. For the first time a dwelling is used as an acoustic barrier to aircraft noise. Here, an attractive multi-story apartment, providing luxurious living in an area convenient to transportation, shields the single family dwellings from the high sound levels produced by aircraft. Thus the barrier protects a multi-million dollar community from noise and at the same time produces income in the form of rentals and taxes on land which would otherwise be depreciated due to excessive noise.

Another factor is the diffuseness of responsibility. For example, who is really responsible for aircraft noise: the manufacturers of the airplanes? the engine manufacturers? the airport owners? the Federal Government? Who knows? This needs to be defined so that we can get to the proper responsible authority, or at least a combined one.

This diffusion of authority and responsibility now encourages a callous indifference by authorities who make plans for airports, freeways, etc.; they give little consideration in advance to the imposition their plans make on the public.

Methods for rating noise have been discussed during these sessions, and some of the speakers have said, "Do not wait for further development. We have adequate information now." I echo that same statement. We so desperately need a firm, line-holding specification, now. However, when we get into discussions we find that what each of us really means is, "If you'll take my standard, we'll all get along fine and we'll have one quickly." It just doesn't work that easily, so let me give you my recommendation: For heaven's sake, keep it simple, by all means. This does not mean that you stop the very essential development of more useful and quantitative standards, but for the moment let's have action and let's have it with a very simple standard.

And another point. The knottiest problem is to determine a "tolerable" noise limit. Continued and repeated attempts, using psychoacoustic methods and public questionnaires, are plagued with procedural questions and uncertainties. Let me suggest that the most reliable method might be to study the severity of public reaction over the years, considering the area and extent of complaints and legal actions. This would seem to be the most practical indicator.

We must beware in evaluating noise complaints of secondary factors, which may, after all, be even more important. One of these is—in the case of aircraft noise—fear; and I am convinced that it is fear which masquerades as complaints against noise. Complainants really think that noise should be ratable more quantitatively. They certainly cannot expect to treat their emotional concern on a quantitative basis, so they blame it on something else. Now, I don't think this is wrong; certainly the noise is important enough, too. But let's always be aware of other factors involved.

What we have is really a legislative problem. It is a creeping noise situation of one dB a year. I won't echo the extreme that many people in our field voice —the hazard to life; I just don't believe it can get that far. Nevertheless, this legal term call *taking* is the problem; I would suggest one way around this is perhaps to invent a new legal term (I'm stepping out of my shoes, but I'm saying this as a team action, so I hope maybe the legal eagles will find a way around this difficulty). Perhaps the term *encroachment* should be considered. I would say that a reasonable basis is this: A resident voluntarily moving into an area accepts the noise state of that area at the time of his arival. But he should not be expected to accept an encroachment of noise from new sources not predictable by him.

Panel VI

Discussion and Summary

Discussion and Summary

Panelists

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KARL D. KRYTER, *Stanford Research Institute, Menlo Park, California*

HENNING VON GIERKE, *Wright-Patterson Air Force Base, Ohio*

LEO DOERFLER, Panel Chairman, *University of Pittsburgh School of Medicine, Pittsburgh, Pennsylvania*

Participants from the Floor

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JOHN M. TYLER, *Pratt & Whitney Aircraft, East Harford, Connecticut*

BRUCE L. WELCH, *University of Tennessee, Knoxville, Tennessee*

DOERFLER: During the course of this conference we have gathered together, albeit incompletely, a surprising amount of information. This information is somewhat scattered and needs to be pulled together, but it is enough to begin to act on, and the action will not be limited to governmental, but will include professional and lay action.

A number of questions have been submitted, and I would like to spend the remainder of the time on these questions, giving any one of you the opportunity to amplify or to repond to the questions, or to make comments.

There is one question that all of us might have some interest in: Why have the automobile manufacturers increased the volume of sound in horns, and what is being done to cut down this volume?

APPS: I'm not aware that horn noise levels have been increased. I do know that, at cruising speeds on expressways or highways, our horn levels, even now, are hardly more than adequate to penetrate into the interior of a car and be heard, so there are problems of reducing horn levels any lower.

Of course, if the levels are increased, then there is the corollary problem that you're adding to the din in cities, where such increased levels are not needed or wanted.

DOERFLER: Is there any hope that a feasible timetable for noise reduction, as suggested by Potter, might be developed on the basis of a desirable overall noise level rather than upon so-called tolerable or acceptable noise levels?

TYLER: The idea of reducing noise on a schedule, for example, 1 dB per year, has been suggested several times. In my paper I mentioned that research on noise reduction has produced results piecemeal and any significant noise reduction involves the contributions of work in many different areas. However, to implement this noise reduction may require the development of a new model engine which takes many years. Thus, noise reductions become available in quantum steps as new designs of engines are introduced, and are the result of research and development work done since the previous family of engines was developed. The engines going into service in the early 1970s incorporate the results of research on noise reduction accomplished in the late 1950s and early 1960s. These new model engines can then be expected to be in production for at least five to eight years.

GOODFRIEND: I'd like to respond in a slightly different way to that question. Unless there are some large steps set down—a schedule for each type of noise source with which we are faced—we will see little progress. We must have motivation; and the motivation for people who make noise is a law or rule, regulation or goal, which says, "You shall make no more than 5 dB less in 2 years and 10 dB less in 10 years." If it means adding some extra weight to aircraft to accomplish this for aircraft noise, then this may be the price we have to pay. I look a little more optimistically at aircraft noise in the light of what the Federal Aviation Agency programs are, but I also believe that you have to set your goals, and you have to put some enforcement behind them.

VON GIERKE: I think the basic question was if one could or should direct a noise control program toward achieving desirable levels right away instead of settling for tolerable or acceptable levels as a first step. Although such a goal might sound very tempting I am afraid it is not very realistic. First, remember how wide the spread of interpretation is concerning what is an acceptable noise. It is, therefore, very difficult to decide what are really desirable levels. It is even difficult to state for one individual what are desirable noise levels; a level might be perfectly desirable at one time but might not at another. Second, the community and the population today are probably different from the community and population of tomorrow; not only the individuals themselves might change but also the plans of the cities, the structures and layouts of the houses, the noise reduction in houses, and the noise sources. All this has an effect on the levels individuals are exposed to. Consequently, I think it would be unrealistic to start a noise control program with the immediate goal being to achieve desirable levels for all individuals at all times. As much as we might wish for such a solution, it can easily be shown that such a solution cannot be enforced overnight: it would mean the shutdown of many industries, a complete change of our transportation systems and of our big cities—in short, a complete change of the technical, urbanized society we have. Although we should not lose sight of the final goal of desirable noise levels for everyone, the only realistic plans and solutions must be along the lines which have been discussed and proposed: one must evaluate what is possible and achievable and try to make gradual progress in this direction.

At the moment I think the certification of aircraft with respect to noise is certainly the first, probably the most important, step toward lower noise levels. But nobody claims or should believe that this will guarantee desirable noise levels for everyone in every home. Probably no realistic restriction of aircraft noise could guarantee this today. And even if we had no aircraft at all, it still would be impossible to guarantee everyone the desirable noise levels that some speakers here have discussed as desirable levels.

In my opinion, it would be a disservice for any noise control effort to talk of goals which cannot be achieved, and thus sooner or later must lead to disappointment and unfavorable reactions. I think it is extremely important to be realistic and to stay unemotional. Many discussions in the past have been on a very emotional basis, and I don't think this helps the cause on either side.

We now see the first signs that something positive is being done and that the individual citizen and the local, state, and Federal governments are trying to attack this highly complex noise problem. Therefore we should see to it that the goals are realistic and, once set, that they are really achieved and maintained. I think this is more important than dreaming about noise reduction goals which are not realistic.

BARON: But who is to define *realistic*? Traditional definitions prevent a citizen from leaving a meeting like this and getting any meaningful action. The community, its legislators and administrators, ask, "What is a *realistic goal*?" Invariably these realistic goals are defined by industry-oriented groups like the Society of Automotive Engineers or the Air Conditioning and Refrigeration Institute. Upon examination they turn out to be defensive standards which merely define and perpetuate the existing noise levels. We need a dialogue on the question of what we mean by *realistic* and on the question of "desirable goals." The public, which after all is the receiver of the noise, must participate in these discussions and be represented in any deliberations that have to do with standards and goals. This applies to the government sector as well as the private sector.

von Gierke: I fully agree with you. McGrath could tell us about work underway to define and evaluate alternative solutions: for example, the solution to the airport noise problem. He has noise exposure forecasts for the areas around New York's Kennedy Airport and other large airports for the years 1970 and 1975. Parallel with these studies, alternative solutions are being studied to reduce the noise-exposed areas and the noise levels. One solution would be to buy all land falling within certain noise exposure criteria and use it for purposes compatible with the noise levels. You immediately realize that this is probably not a realistic solution at the moment and will probably not be for some time to come. Another equally unrealistic solution would be to restrict air traffic from one day to the next so that noise levels would not exceed levels rated desirable by everyone involved. Realistic solutions, though, must be somewhere in between. Providing alternative solutions is a scientific, technical problem; the citizens, the legislature, and the administration make the choice between alternative solutions by weighing costs versus benefits.

Baron: I don't live over a superhighway, but I am somewhat familiar with one such project. I believe it's called the Bridge Housing Project and it was built above the approach to the George Washington Bridge in New York City. Noise—and air pollution—were ignored in this state-assisted housing project although it was hailed as one of the most progressive planning concepts in years.

After the initial leases expired the tenants raised an outcry demanding that something be done. They didn't want to move, but they complained they were being "poisoned by pollution from traffic and going crazy from its noise."

They got no satisfaction from the management and finally won the interest of the late Robert Kennedy. His research staff came to Citizens for a Quieter City for orientation. From discussions with his staff and from newspaper reports there is no question the tenants were very disturbed by the noise. I don't know what finally happened, but I do know that a similar project is planned over the tracks of the Pennsylvania Railroad, in Manhattan. We are concerned. What acoustic standards, if any, will be applied? Who will see to it that the human environment is shielded from the intrusive noises of the railroad, not to mention the "normal" noises from traffic, helicopters, STOL-craft (short take off and landing craft), ad nauseum. At this time in history there is no guarantee that the Bridge Housing Project fiasco won't be repeated.

Beranek: This question doesn't have one answer, because it's possible to design homes and buildings to keep out aircraft and highway noise. Hotels have been built at airports all around the country—Los Angeles and Washington, for example—that are quiet inside. The question is whether or not the architect and the owner recognize that they have to provide a different kind of construction in a near-airport or near-highway environment.

The general question raised by Baron is very important. I would like to say a word about some problems he faces as a part of a Citizens Committee. First, I believe Baron would say that when he asks for information—for example, information on the heliport on the top of the Pan-American Building—about the measured noise levels, interference with speech, or interference with sleep, he feels he's confronted with a wall of fog—a hiding of information—that makes it impossible for him or other citizens to judge the merits of a case. I think we, as scientists, ought to present to the public, as well as to interested commerical parties, enough information so they know what to expect.

A second point is that society, represented by our Congress and state and local legislative bodies, has to decide what's important in life. As Henning von Gierke has said several times, this is not the job of the scientist; we as scientists should present only the facts and the alternatives. Then, in the political arena, the people should decide whether they want fast transportation, such as the supersonic transport with its booms; whether they want to live next to airports and have lower transportation costs, and so on. These matters are not for scientists to decide. Choices of commerce versus the "good life" are in the political domain. We should strive to make information available and let the political world decide where society's values should lie.

KAUFMAN: We live in the age of the gap, the missile gap and many other gaps. I think there's a gap between what you, as scientists, feel, and what the legislatures and Congress know about your feelings. The question we're confronted with is bridging that communication gap.

So the real question is, once you've decided on minimums, something we might work with, then go the next step to bridge the gap, so that we may provide the legislators, the Congressmen, with the material to do their job.

DOERFLER: Back to automotive noise. Why such high noise levels from trucks accelerating on a two-degree grade on the city streets?

APPS: The levels of many vehicles heard on the highway today represent levels that are higher than new vehicle levels. Veneklassen touched on this, and confirmed my position: I submit that the new vehicle levels are not maintained once they're in the hands of the operators. If a person buys something, it is then his. And I think all of us who have slept in motels near a highway or freeway, those of us who are pedestrians or live near a freeway, can cite hundreds of instances of vehicles going by and hearing the tires sing literally for miles, or hearing a loud exhaust coming for miles. When this happens I am personally convinced that I don't need a sound-level meter to find out if 125 sones, or 88 dBA, or whatever has been exceeded.

Now, whether or not this is the kind of truck that Baron has observed going up this 2° grade, I am not sure. I rather suspect that it is a truck that is not in the condition that it was when it left the factory.

DOERFLER: If an industrial doctor asked what damage risk criteria (DRC) he should follow to protect workers in this plant, what curves should he follow? There are at least three known curves of DRC: One shown by Miller, one referred to as ISO (International Standards Organization), and one which is practically flat at 85 dB.

Miller: I would follow the one that we recommend, but they're all close enough so that you come to effectively the same decisions.

Glorig: I think that one of the problems encountered, in trying to set DRC curves, is that industry, in a great many instances, doesn't want to be told which curve they should use. What they seem to be more interested in is how much risk is involved as a function of level. The recent attempts at setting standards are to present a series of levels accompanied by risk, as a function of exposure time. At 80 dBA, there is no risk; as dBA levels increase, the risk increases.

Now, those of you who are knowledgeable about this problem will say that there are many other factors to be considered, such as time and susceptibility. But, if you consider that a hearing conservation program should be initiated any time the level exceeds 85 dBA, it doesn't matter much about exposure time because people are not going to use ear protection for five minutes, and then remove it for ten minutes, they're either going to wear ear protection or not.

Actually, energy and time can be inversely proportionate; as energy goes up, time does down. Proposed standards make use of this principle. I have to admit that some of the proposed standards have been somewhat complex, and sometimes a little difficult to use in an industrial situation. But the standard, after all, is a guide, and the user must have sense enough to realize this and relate it to his own problem accordingly.

Doerfler: Is the electroencephalogram (EEG) amplitude proportional to the intensity of the stimulus?

Jansen: We did our investigation with 55, 60, 70, and 80 dB, and we could record the different changes in sleep. But it was only useful to have these stimuli within the deepest stage of sleep; if there was a flat stage of sleep we always found that the tested persons awakened.

Doerfler: Is there any research being done in the United States on physiological effects of noise other than on man's hearing, as there is in Jansen's laboratory in West Germany?

Kryter: I don't know of any research specifically like, or following the pattern of, Jansen's. I think we should be doing this type of research. There is research being done on some physiological effects of simulated sonic booms and other noises (particularly subsonic aircraft noise), and upon people when they're asleep. The physiological measures being used are the EEG, behavioral awakening, and skeletal muscle tension.

Glorig: Along the same lines, we have taken a precursory look at industrial records of employees' annual physical examinations to see whether employees who work in noise end up with higher blood pressures, or more coronaries, or more accidents, or more this, that, or the other. This is strictly preliminary but, as far as we can tell now, there isn't much difference.

VON GIERKE: I might mention that there is some work going on in Canada by Thiessen and others along the line of Jansen's work. They are investigating the effect of traffic noise on sleep, by means of electroencephalography and by studying other physiological variables. At our laboratory some work is in progress on the physiological effect of high intensity noise. These studies are not necessarily related to traffic noise exposures, but are concerned with exposures to considerably higher levels, for instance, in some industrial and military situations.

DOERFLER: Is a comprehensive legal study necessary regarding problems of noise?

KAUFMAN: Yes. I know of only one legal study done; it is by Spater, in the *Michigan Law Review*. I think it would be helpful for lawyers who will eventually have the task of aiding you and all of us in making workable statutes, to have a comprehensive, in-depth review of all the laws of nuisance and annoyance related to noise.

DOERFLER: Would you comment upon whether noise disturbance as a nuisance should be compensable to those arriving after the noise source?

KAUFMAN: This is the person who comes in after a noise disturbance is in a neighborhood.

The law is that damages are not recoverable for mere annoyance. The courts will not grant an injunction if there would be undue hardship worked upon an existing business that is causing noise disturbance to a claimant who is new to the neighborhood. On the other hand, if a business causes a substantial decrease in the value of the plaintiff's property, or a material discomfort to the plaintiff, it will be enjoined on the following two conditions: (1) if the annoyance is due to poor design or improper operation of the defendant's facility, and can be abated by the adoption of an improved design or operation, and the improvement is one that would be commercially feasible; and (2) if the activity creating the noise was established in a neighborhood which was obviously inappropriate for that activity.

DOERFLER: Research has shown that recovery from temporary threshold shift (TTS) occurs in a much shorter period of time than six months. In dealing with claims for noise-induced hearing loss, you stated that you favor the six-month rest period before the evaluation. Why? Doesn't this waiting period discourage the worker from filing a claim during his working lifetime?

GLORIG: Here is how the six-month provision originated: In early cases in New York State the insurance companies and industries were afraid of large, accrued liability that they would not be able to take care of if they were flooded with claims, and there was nothing to prevent this as far as they could see at the time. There was some unsupported medical opinion then that if you removed a man from a noisy job, it would take approximately six months to stabilize his hearing loss, and, therefore, no compensation should be paid until the end of that time.

New York proposed this, but when they got down to arguing about it, some of our research showed that it only took about 10 to 14 days to stabilize the hearing loss, and that, really, the six-month period should not be based on a medical reason. Thus, it was included for a socioeconomic reason: to prevent an overwhelming accrued liability.

Some of the states have the six-month provision; some do not. California, for example, does not, but is considering it now. The reason is this: if you do not have a provision of this kind, a man with a progressive hearing loss can file a claim every time he needs a new television.

DOERFLER: Is anyone in a position to acquire data on the levels at which noise becomes distracting, measured by ambient levels and accident rates in research laboratories? Reasons for choice of research labs as subject matter are as follows: (1) The experimenter's attention is more likely to be stressed near the limit because operations are not completely specified. (2) Hazards are not a matter of prior experience. Another section of this question: shouldn't the error rate in computer lab operations before and after lowering sound levels by proper isolation and treatment be examined?

COHEN: We are doing some work with noise effects on vigilance at our laboratory, and we find we have a double vigilance situation, because the technicians apparently can maintain attention themselves for only a certain length of time. They have to get out and get a change of stimulation, and, as a result, we have problems in evaluating the data due to errors in record keeping, or something of this nature. I am not sure this is a noise-induced case; I just think that, in covering a test situation like this, it is quite tedious.

Regarding the second part of the question, error rates in computer operations, we attempted to do some work using IBM keypunch operators. We gave them glass-down and Flents, which are wax-impregnated cotton plugs, to reduce the ambient noise level to see if it would improve their efficiency in keypunching. The testing was of a cyclical nature: for a week they wore the ear plugs, for a week they didn't. This schedule was repeated, to take the novelty out of the situation. We found that, after about two complete cycles, many of the workers would no longer wear the ear plugs. Apparently, they proved uncomfortable, or interfered with conversation. I guess the rumors couldn't spread as usual. Our experiement went out of control because we could not always tell when workers were using the ear plugs and, consequently, we could not evaluate performance under these conditions.

PICKETT: There is quite a bit of laboratory work on the effects of noise on attention, and on tasks that demand continuous attention, such as vigilance, i.e., detecting a rare event. I'm not very familiar with this work, but a few years ago, Donald Broadbent, at the Applied Psychology Research Unit, Cambridge, England, was very active in this research, so if you're searching the literature for good research on this subject, that's the first name to look for. I believe in the Toronto Defense Research Labs they've done some work on this, too.

So there is work being done on the problem of vigilance and noise, and attention in noise.

DOERFLER: Everyone talks about very loud noises. However, in recent years, the steady background noise in many city environments, both indoors and out, is the sound incidental to large-scale air conditioning equipment. In some instances it is clear that designers have not made the best possible use of duct areas and fan blade speeds to lower the noise levels. Who is doing any official work to regulate this?

GOODFRIEND: The various engineering groups involved with fans, ASHRAE (American Society of Heating, Refrigerating, and Air Conditioning Engineers) and AMCA (Air Moving and Conditioning Association), have standards for the measurement of noise from various air conditioning devices. Indoors, what noise levels should be in what spaces, and out of doors, what noise levels are permitted, come under two other jurisdictions. The outdoor noise levels may fall under a municipal regulation. There are guides in the Heating-Refrigerating-Air Conditioning Guide and Data Book, which are recommended practice both for indoor and outdoor sections of equipment. They may not be completely adequate for all spaces, but they are a yardstick. The manufacturers, however, are limited to the method of measurement provided by the ASHRAE 36 standards. There are two different ones, Number 62 and 63, for two different purposes, and there is an AMCA standard which they require for measuring unit heaters and air conditioning terminal devices. There is continuing research on this. A large number of air conditioning companies and several universities are working on this.

DOERFLER: What are the effects of sonic boom on the sleeping state?

KRYTER: There will be a report issued shortly by the National Aeronautics and Space Agency (NASA) about this. A small bedroom which could be agitated by a simulated sonic boom was built in a laboratory. Subjects were allowed to sleep in this room for a number of nights. During this time repeated sonic booms and some subsonic aircraft noises were administered and their effects (electroencephalogram and behavioral awakening) were studied. The results, to date, are tentative, because of the small number of subjects, and because the subjects were not adapted as much to the subsonic noise as to the sonic boom. The results are perhaps somewhat unexpected: In the daytime people judged the noise from a 707 jet of about 110 perceived noise level (PNdB) to be equal in acceptability to a boom of about 1.7 sounds per square foot (psf). At night, though, the boom came off somewhat better; the tentative data show that approximately 103 PNdB for subsonic noise gives about as much awakening as a boom of 1.7 psf.

Doerfler: Certain Federal agencies are charged with determining the potential health hazards of the supersonic transport (SST). Why have they not conducted research, either with experimental animals or with humans, to study the long-term effects of repeated exposure to high-intensity impulsive sound? Why are the medical and research officers of these agencies not acquainted with the basic medical literature demonstrating ill effects other than the effects upon hearing of high-intensity impulsive noise?

Kryter: There are two answers. One is that there seem to be enough reasons for anticipating that the public will reject the SST because of the sonic boom, without getting the types of data that are alluded to; that is, with the research results obtained with people themselves, the question has been answered.

The second reason is that in the research literature referred to it is hard to find data that are not open to serious question, with respect to their relevancy, or else the data show no negative effects. It can be noted, for example, that people living near and working on gunnery ranges show no particular evidence of any adverse physiological effects from the impulse noise other than in their ears.

There is a small change in blood flow in the periphery of the body and the heart rate and blood pressure increase in response to acoustic stimuli and other stimuli, but that is something that occurs all the time and is probably not harmful. Also, there is, perhaps, more habituation than we realize. I'm reminded of the fact that R. C. Davis found two types of startle responses to impulse noises: one response, the larger of the two, adapted out very quickly to repeated impulses; and the second response, (one that's very reminiscent of the response that Jansen has mentioned) is a small, rather long latency response that did not adapt so completely. The question is whether these smaller responses wear out the organism or merely represent a normal exercise of some of our body functions.

Doerfler: Leonard said compensation for hearing loss should be delayed until the worker has quit his job or changes employers, because industry cannot pay for work and inability to work at the same time. How can this idea be reconciled with compensation for facial disfigurement, which is widely paid after accidents, even though the employee continues to work?

Kaufman: I am not sure they can be reconciled. I think the ideas are inconsistent. We have the normal schedules of workmen's compensation; we have the normal disabilities, and once found, the worker can continue to work. The theory here is compensation, and there's no fault criteria. Now, if you go into the question of a six-month delay or a termination point from employment and from injury, so that you have a loss of wages predicating recovery under workmen's compensation, I think that's a different question. But I don't think the two points raised by the question are reconcilable.

Hirsh: Leonard did not mean to enounce as a principle that you could not pay for the work and compensate for hearing loss, but rather that the industries involved couldn't afford both. There are two additional questions. If we cannot legislate a desirable environment, is it possible to at least define through legislation what are the various desirable environments effected by zoning in a community? The second question is, what Federal agency might be in a position to do this?

I am not an expert on what you can and cannot do through legislation. But we could certainly act upon the suggestion contained in the first question, namely, to set up different degrees of environmental quality, perhaps in the form of a recommended practice or in the form of a guideline that could be provided by some Federal agency to regional, state, or local agencies. It is already done in some cities where the noise requirements, for example, for a purely residential area are not the same as for an area labeled light industry.

Now, what Federal agency might be in a position to do this? I suppose, since the Public Health Service defines hazards to public health, it could do so if it had appropriate agencies and personnel. I know it is within the scope and intent of the Office of Noise Abatement in the Department of Transportation to provide such guidelines, but I cannot comment about legislation.

KAUFMAN: This might be an appropriate point to mention Kupferman's bill, because this bill deals with noises in general and would provide an Office of Noise Control. This office is not envisioned as a regulatory office, but is to be a national clearinghouse for the dissemination of information about noise to states and local governments. For example, in Washington, D. C., there is the National Association of Municipal Law Officers. It has model municipal codes that can be suggested to local units of government. I think we can accomplish the writing of quantitative measures in codes if we accumulate information from legal and legislative sources, feed it to state and local governments, and let them write the model ordinances.

DOERFLER: Do any damage risk criteria exist for ultrasonic noise?

VON GIERKE: There are no specific damage risk criteria for ultrasonic noise. Actually, there is very little evidence of any damage to man from ultasonic noise exposure. I think the best summary of the known and the unknown in this area is an article by Parrack [Parrack, Horace O., Effects of air-borne ultrasound on humans. *Internat. Aud.* 5, 294-308 (1966)]. I think this article summarizes what is known about possible damage from ultrasonic noise, including laboratory experience and what protection is recommended.

Yet there are practically no known injuries arising from human exposure to airborne ultrasound.

WELCH: I would like to challenge two statements made by Kryter. Here, in essence, is what he said: (1) There is no evidence that the sonic boom will have harmful psychological and physiological effects upon humans. (2) The ignorance on the part of Federal agencies about experiments on the phychological and physiological effects of high-intensity impulsive noise upon animals which exist in the basic biomedical literature is justifiable because the reports are hard to find.

I believe it unjustifiable to say there is no evidence that repeated subjection to sonic booms will have adverse effects. In truth, no effort has been made to determine whether harmful effects will be produced or not. I believe that whenever the introduction of a major technological change of our environment is anticipated, we have the responsibility to find out in advance whether harmful effects will be produced or not. Public acceptability (or tolerance) is not an adequate criterion. Even if the public will accept the change, even if the public is unaware of the change, we nevertheless have a responsibility to determine, in advance, the potentially harmful effects of any new technological innovation.

I find Kryter's excuse that the basic medical and biological literature is hard to find to be both incredible and totally unacceptable. The biomedical literature contains an appreciable amount of evidence from experiments conducted upon laboratory animals under well-controlled conditions that demonstrates that high-intensity impulsive noise, of lower intensity than that produced by expected sonic booms, has teratogenic effects upon animals that are still *in utero* and has detrimental cardiovascular effects upon adults. I do not say this happens in humans. But I must say I am disappointed that in correspondence conducted over the past two years, I have been unable to obtain this information from the Federal agencies responsible for determining if such effects might be produced.

In the normal course of planning their program of research and evaluating the relevant factors to be considered, why have these agencies not gone to the library and found this information for themselves? Why have they not taken these reports into account and designed experiments to test their validity? If a drug has been reported to produce the same adverse effects upon experimental animals that high-intensity impulsive noise has been reported to produce, the FDA (Food and Drug Administration) would require extensive long-term experiments to carefully study these potential effects over the lifetime of experimental animals. Such animal experiments have not been conducted and none is planned; detailed experiments on humans have not been conducted and none is planned. The scientists responsible for evaluating the potential effects of exposing the human populace to sonic booms several times each day for a lifetime are not even aware of the technical scientific reports suggesting that detrimental effects may be produced. And Kryter tells us that their ignorance is justified because these reports are difficult to find! In the first place, such information is not difficult to find; if one spent a single afternoon looking for it in a good medical library it would be virtually impossible to avoid finding it. In the second place, when one is planning a research project, difficulty is no excuse for failing to find existing relevant publications and using them as a point of departure for the projected research.

The difficulty of finding basic information, particularly when the responsibility to the public is so great, is not an acceptable excuse. The responsibility to find it and to test its validity rests with us.

KRYTER: I think my previous comments were somewhat misunderstood, or weren't all heard.

There are noise impulses present in our society, and have been for hundreds of years, that are of much greater intensity than that of the sonic boom. As a matter of fact, a door slamming in some rooms will create a greater pressure wave disturbance than the sonic booms anticipated from the SST. The overall sound-pressure level of the anticipated sonic boom from the SST will be about 130 dB. The overall sound-pressure level of a gun noise, which has energy and frequencies that are much more significant to the ear and the organism, are between 150-170 dB. Evidence about responses to noise impulses on human beings living in typical everyday environments indicates that we really don't have to be concerned about damaging the human organism physiologically by the boom from the SST; or at least the boom is not going to damage the human organism any more than it's being damaged by many acoustic impulses it receives in daily living.

I hasten to say there is no question that sound, particularly if unexpected, can cause the heart rate to change, can cause blood pressure to change, etc. If you slam a door this happens; if you drop a glass, this happens; if you have a sonic boom this happens. But I get the impression the questioner thinks this means people are being made unhealthy by these daily occurrences and that before one can introduce a noise (say, the SST boom) that is no more intense than other noises accepted in our society, we need to perform an extensive general health-test program on animals and humans.

In my opinion this is a kind of critical mass of the masses which can use our normal law procedures for settling public issues of the type we are faced with because of the SST; it can cut through all the complexities and the inertia present in our Government. The fact that 30% to 50% of 50 million people will feel that the sonic boom from the SST is uncivilized (and the research data indicate that this is exactly what they will feel) means our government and industry will get the message and act accordingly.

So I do not feel the despair or pessimism that Ferry feels. The research results show that people, when exposed to the SST booms, if present in the number planned, will think the sonic boom and the SST inordinately unacceptable in our civilization as normally defined. You can and, for the good of the public, perhaps sometimes must discomfort a couple of hundred-thousand people in this country, but not millions. This is the real issue, and I think basing the argument on subtle, and in my opinion, not really medically significant, evidence is unnecessary and, in some respects, not objective. There is enough research data available to settle the question of the acceptability of the sonic boom without having recourse to arguments and data that are perhaps hard to justify.

VON GIERKE: Ultrasonic damage was a popular subject right after the war, around 1946 and 1947, when (in connection with the introduction of jet aircraft) numerous rumors appeared in the press about ultrasonic sickness and the effect of ultrasound on the nervous system.

As far as I and many other people could find out, these rumors were completely unfounded. For about 10 years the Federal government supported fairly extensive research programs in this area, and funded any reasonable proposals from universities or other institutions. The results were overwhelmingly negative, and I want to refer you again to Parrick's article on the subject. In most cases when one tried to study the effects of ultrasound in noise situations occurring in the field, audio-frequencies present in the overall noise spectrum produced the effects attributed to the ultrasound. This is why, after approximately 10 years, this research was terminated in favor of other problems much more significant and deserving of more study.

Results of animal experiments with ultrasound do not necessarily apply to man. We know that many animals, particularly small laboratory animals, are more sensitive than man to sound, in general, and particularly to ultrasound. Animals have a higher hearing acuity in the higher frequency range; therefore, animal studies are of limited value. If you consider doing human experiments you have to weigh the payoff from exposing humans in research studies against the actual risk that people are exposed to in their daily lives.

I agree that if we introduce new technologies we have to see what the by-products are, and how they could interfere with human living and health. With respect to ultrasound, there are no widespread ultrasound sources now which would justify an extensive research program. Yet there are some ultrasound sources in industry, particularly in manufacturing processes, which deserve protective measures. However, ear protectors or other protective measures used against audible sound give even greater protection against ultarsound; so protecting industrial workers is not difficult.

The problem is different if ultrasound is transmitted through liquids or through solid structures. For such ultrasound exposures, which occur in connection with industrial cleaning processes and with other machinery, it would be desirable to have better safety criteria. However, this leads us into a completely different area: vibration exposure, i.e., exposure of the body to vibrations.

LIPSCOMB: As an extension of this question, isn't it appropriate to consider the ultrasonic-frequency rise-time components of impulse noise?

KRYTER: You are speaking about the impulses which reach the levels of 160-170 dB. If you look at the frequency spectra of these impulses you will find that they fall in frequency regions where the ear is very sensitive. However, these are not primarily in the so-called ultrasonic regions. The peak energy in the impulse from a gun will usually be at about 2000 Hz, or so, and then fall off. There is often appreciable energy to 250,000 cycles, but it is decreasing at approximately 6 dB per octave beyond 2000 Hz.

Coles: In the last two years at the Institute of Sound and Vibration Research, University of Southampton, England, we have done a study on the effects of ultrasound on the body and on hearing. Acton has looked at a number of ultrasonic sources in industry of which there had been complaints of nonauditory symptoms from the employees. The symptoms were nausea, headache, fatigue, and ringing in the ears (tinnitus). His evidence agrees with what von Gierke has stated: People who have these symptoms only get them when the ultrasonic noises have major components in the 16,000 Hz octave band. [Acton, W. I., *Ann. occup. Hyg.*, 11, 227 (1967); and Acton, W. I., and Carson, M. B., *Brit. J. industr. Med.*, 24, 297 (1967).] A level of 75 dB in the ⅓-octave band centered on 16,000 Hz would appear to be the criterion below which only a minority of people (5%) are likely to have complaints from ultrasonic noises.

Acton and Carson did audiometric measurements of temporary and permanent threshold shifts in people exposed to industrial ultrasonic noises and were unable to demonstrate any auditory effects attributable to these noises. H. O. Parrack [*Inter. Aud.*, 5, 294 (1966)] has reported TTS (temporary threshold shift) from ultrasonic noises that occurred at aproximately subharmonic frequencies when the noise reached a very high level. This seems to link up well with recent animal work of P. J. Dallos and C. O. Linnell [*J. acoust. Soc. Amer.*, 40: 4, 561 (1966)] in which subharmonics from high-level ultrasound have been demonstrated in the external ears.

Linking his own data with that of Parrack and of Dallos and Linnell, Acton has suggested a criterion for harmful effects on hearing from ultrasonic noises of 110 dB in ⅓-octave bands at or above 20,000 Hz.

Doerfler: Is there an approved program to train industrial audiometric technicians?

Coles: Yes, there is such a program. It was developed by an intersociety committee composed of representatives of the American Speech and Hearing Association, AAOO (American Association of Ophthalmology and Otolaryngology), the Industrial Medical Association, and the Industrial Nurses Association. You can obtain information about it by writing to any of these associations. I believe it is a two-and-a-half day series of lectures and demonstrations, supervised practice, and so on.

Doerfler: Can someone relate the magnitude of likely sonic boom to the natural sound of thunder which is categorized as an act of God?

Kaufman: I really think there's no question about the fact that certain things in law are considered acts of God, like lightning and thunder, and victims cannot realize a monetary award. But the sonic boom is man-made, and therefore an act of God would not be a proper defense, in my judgment.

Doerfler: Before we end this session and the Conference, Hirsh will make some concluding comments.

HIRSH: I would like to draw some conclusions from this Conference, particularly in light of what was hoped for by the Planning Committee, of which I was a member.

Beranek drew a range extending from 80 to 130 PNdB, which he described as going from a barely noticeable noise to an intolerable one. This range of 80 to 130 PNdB is roughly a range from 70 dBA to 120 dBA. In Botsford's comments we learned that 90 dBA is characteristic of the median factory noise. Roughly 50% of the plants he investigated were noisier than 90 dBA. In the comments of Soroka and Grandjean, we encountered a range of community noises running from the very pleasant environmental recommendations in Switzerland of 35 dBA or 45 dBA up to 90 dBA in some parts of San Francisco. We know, from the several reports given by Kryter, Pearsons, and others concerned with aircraft noise, that levels of the order of 100 dBA are not uncommon under the flight paths of airplanes.

We know from Webster's paper and others, which related some of the earlier work of Beranek and of French and Steinberg, that noises of 65 to 70 dBA will interfere with conversational speech, this is at ordinary speaker to listener distances of 3 to 6 feet. In short: this ordinary conversation is difficult near many room air conditioners, in the patio next to your neighbor's outdoor air conditioner, in homes or in schools within several hundred feet of express highways, and, furthermore, conversation will be virtually impossible in about half of the noisy factories, many military environments, within 100 feet of an express highway, and within a couple of miles of airports under flight paths.

Finding a site for a new school or a new home is some urban or suburban area, in what we would call a satisfactory environment sufficiently far from large air conditioning installations, highways, flight paths, factories, and power transformers is getting to be difficult indeed.

Hearing damage is a problem in some of these environments and—as you heard yesterday from Ward, Miller, and others—difficult to predict, particularly when rest periods or infrequent exposures are involved.

But we did learn from these gentlemen that if we use a base of 65 to 70 dBA for potentially interfering noises in ordinary speech communication, there is still a 20 dB margin between this and a hearing damage level.

Now, all other physiological effects (e.g., stress, too frequent arousals, etc.) are clearly measurable at levels above 90 dBA, and are noticeable from 70 dBA. We do not know very much about long-term cumulative effects.

Brief exposures, not damaging to hearing and not long enough to interfere with substantial amounts of speech, are troublesome on other counts. This applies particularly to aircraft noise and sonic boom. They don't last long enough to demonstrate substantial interference with long-term speech communication and, unless their levels are extremely high, they don't last long enough to damage the hearing. Yet they appear to be troublesome; they appear to be annoying; and people react negatively to their presence. It is in this area that we have the difficulty of nonacoustic features, which you may call unexpectedness or meaningfulness.

Ward has told us that these characteristics are probably not important with respect to hearing damage. They become important in connection with speech interference, as distractors, and because of the special conditions that obtain when you interfere with speech communication by the presence of irrelevant speech.

Annoyance and physiological reactions are probably the area in which these kinds of effects are most severe, and least understood.

Regarding social and legal implications, it is quite clear that the employee's hearing has become the responsibility of his employer, at least in most states, and, as Botsford suggested, this responsibility must now be shared by the manufacturers of the machines the employer uses.

Kaufman has told us about the taking of property for public use. He has told us that individuals have essentially lost the right to the air space above their properties, if that air space happens to be navigable by aircraft.

An increase in social planning appears to accompany an increase in population. Thus it seems to me there will be more and more categories of what will be called "public use," and therefore there will be more and more taking of individual property. The individual and the small community cannot act effectively, mostly because they have to act against large interests; I suppose it is for this reason many have suggested that Federal regulations or guidelines be used by regional or state authorities.

There are city ordinances that specifically outlaw nuisances but it's very difficult to define a nuisance quantitatively; nuisance in the court today must be defined in terms of a judgment.

Laws can be invoked to protect one from bodily harm, from inability to work; as Kaufman has told us, laws can also be invoked to regulate not only bodily harm to persons, but also the unusability or the decrease in property value.

In spite of a rather eloquent paper by Oliver Wendell Holmes in the early 1900s, it appears to have been difficult to legally implement protection of privacy when such protection involves such abstractions as interference by noise.

There have been many remedies suggested for unwanted noise. One remedy is to outlaw offensive noisemakers. This remedy appears to be unacceptable to many manufacturers. We have had several suggestions that the technology for quieting machines is available, and we also heard from Benson that the design of enclosures in which man lives and works can help protect him from the noise of machines. (I would like to write the criteria based on a man who stays outdoors or leaves his windows open.)

There have been suggestions about the location of people and noise sources in the context of zoning and transfer of activities. My observation on these procedures as they have been used so ar is that one does, indeed, have to run like hell in order to stand still.

There is the possibility that we can change people's criteria for comfortable existence: in short, make them like it. But I suggest that there has been too much of this already.

One of the most promising remedies we all appear ready to work for is the suggestion that if we in the scientific professions can set reasonable and well-defined limits for the manufacturers, they, then, will have design goals, and the situation will improve in the future.