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The National Measurement System for Acoustics

David S. Pallett and Marilyn A. Cadoff

Applied Acoustics Section
Institute for Basic Standards
National Bureau of Standards
Washington, D.C. 20234

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U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, ***Secretary***
Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, ***Acting Director***

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PREFACE

This report was initially prepared during 1974 in response to a request from the Institute for Basic Standards office, and was intended to be, primarily, an internal, working document. Thus, the NBS role in the national measurement system for acoustics has probably been emphasized to a greater degree than what, in reality, actually exists. Also, because the field of acoustics is a dynamic, rapidly changing area, certain information contained in this report may rapidly become outdated.

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EXECUTIVE SUMMARY

This report describes acoustical measurement processes that are motivated by societal concern over noise and which are continuations or extensions of traditional acoustical measurements. In addition, material is presented to describe an important relatively new application of acoustical technology, the field of ultrasonic non-destructive testing.

Acoustics, the branch of science dealing with sound, has become a field that is an important element in many aspects of our contemporary technological society. Acoustical measurements are performed in order to quantitatively characterize noise levels, to specify noise emissions, to specify the acoustical properties of architectural materials, and to quantify and interpret human response to sound, to name but a few examples. Applications of acoustical principles to be found in other aspects of our technology include the use of ultrasonic acoustic energy to identify and characterize flaws. These ultrasonic measurements are performed in order to meet the increasingly severe requirements for mechanical integrity and reliability as well as in response to pressure for material conservation and increased productivity.

Although the report describes a diverse range of acoustical measurement tools and methods, there remain numerous acoustical measurements not covered in this report. These deliberate exclusions were made for two major reasons. First, resources -- in terms of available time, manpower, and funding -- were too limited to carry out the comprehensive literature study which would have been required to survey adequately such a broad topic as acoustics. Secondly, it was decided to direct attention to those areas in acoustics in which the necessity of obtaining increased objective quantitative knowledge has recently become apparent, and that is primarily in the area of noise abatement and control.

The principal user groups for noise measurements include various departments, agencies, and laboratories of Federal and State governments; manufacturers of measurement instrumentation, products for which noise emissions are of immediate or potential concern, or architectural materials; acoustical consultants, architects, and urban planners; and university faculty and staff members affiliated with research laboratories or speech and hearing clinics. Users of ultrasonic non-destructive evaluation equipment include the aerospace, power generating, construction, metals production, auto manufacturing, metals fabrication, and railroad industries.

There are numerous identifiable social, technological, and economic impacts for these measurements. Measurement of noise is now an important element in the protection of hearing. Conduct of some ten to twenty million annual audiometric examinations will soon demonstrate an increased level of awareness of the effects of noise and of the importance of hearing preservation in our society. Acoustical measurement processes are explicitly involved in noise control and hearing preservation. Economic impact is more difficult to assess quantitatively, and a well-defined picture of the economic impact of acoustical measurements is not yet available.

The work of the National Bureau of Standards in acoustics and its role within the infrastructure of the National Measurement System is based primarily upon a number of interactive processes. The substance of the interactive process consists of such elements as provision and interchange of test and calibration data and technical reports, as well as the development of calibration and test procedures and measurement methodologies. Participants in this interactive process include standards organizations, various industrial representatives (including trade associations and individual manufacturers), professional societies and universities, and even representatives of foreign laboratories. Because of the increased legislative attention given to noise and its control, and the consequent promulgation of regulations that require measurements for enforcement, the adequacy of required measurement methods is now the subject of intensive study, both within NBS and within other Federal, State and local agencies.

The study indicates that there is a continuing demand for improved accuracy and precision in both the development and calibration of acoustical measurement

instrumentation and in the evolution of improved measurement methods. Research in these areas has traditionally been a strength of the NBS program in acoustics. The study also illustrates that a significant increase in the number and scope of legislative actions directed toward noise control has taken place. State and local governments are becoming active participants. Inconsistencies in the relevant measurements required for effective implementation of these regulations introduce ambiguities. These ambiguities also involve the imprecisions inherent in these measurements. Consequently, inequities in trade can arise. A need, therefore, is shown for acoustical research directed toward the basic physical phenomena, the study and evolution of improved measurement facilities and instruments, and the improvement of the required measurement methodologies.

1. INTRODUCTION

1.1. Importance and Status of Field

Nearly all of us are able to speak, to hear, and to interpret sounds. The importance of sound to man's existence is attested to by our possession of the ever-present sense, hearing, and we continually make use of our sense of hearing to provide us with information from which we attempt to infer information important to our existence. Sound is, therefore, a physical phenomenon of basic concern and importance to man.

The more complex civilization has become the more sound sources have come into being. Many of the sounds do not convey desirable information and have little aesthetic value. They are unwanted sound or noise. Man's objections to, and attempts to control, noise have intensified as sources proliferate and the noise level surrounding man has increased.

Central to our technological concern with the phenomena of sound is the necessity for accurate quantitative measures of the relevant physical phenomena. Accurate measures are essential to the design of acoustical devices for communication systems, the improvement of systems for the recording and reproduction of sound for entertainment or aesthetic value, and facilitate the implementation and enforcement of noise control measures. In short, acoustical measurements are central to many portions of our current technological society.

1.2. Purpose of the Study

It can be appreciated that measurement is one of the fundamental activities upon which human cultures depend. It is essential for the establishment of objective quantitative knowledge. Without quantitative knowledge, many human activities would become impossible or would have to be drastically changed. It is therefore appropriate, that the staff of the National Bureau of Standards review the role of some of the more important of the acoustical measurement processes.

All active scientists or engineers are at some time or another concerned with the process of measurement. Conduct of a measurement operation makes one a participant in the National Measurement System. As members of a system which has its own ordered structure of rules, definitions, and procedures for guidance in the conduct of the measurement process, it becomes advisable for the participant to explicitly understand the structure of the system. For without this explicit understanding, the participant cannot identify other individual or institutional participants or user groups, and cannot effectively interact with the system to improve his measurement process or operation.

By making clear the individual's role in the National Measurement System, several advantages of an institutional nature accrue. This particular study is motivated by a desire to identify the measurement system elements and interfaces between the National Measurement System and NBS. As the measurement system infrastructure becomes apparent, social, technological, and economic impacts are delineated. In the process of defining the system structure, current measurement challenges are identified. These data are intended to enable optimum allocation of funds, evaluate current programs in the light of new information, and plan future directions. Perhaps, above all, those involved in defining their individual or institutional roles in the National Measurement System will become motivated to redirect their activities if indicated and thus, to interact more effectively.

1.3. Scope of the Study

Primary emphasis is placed on identification of relevant measurement processes and units, description of the measurement system infrastructure, and indication of the impacts of these measurement processes upon social issues, current technology, and economic processes. Forecasts of possible and probable changes in both the National Measurement System and the interaction of NBS acoustic personnel with this system are presented. Attention is directed to the following topics:

(1) Measurement of sound pressure level and related quantities, and the development and calibration of the associated instrumentation.

(2) Measurement of the acoustical properties of architectural materials and systems.

(3) Measurement of human auditory acuity, especially audiometric

measurements and the calibration of the components of that measurement system.

(4) Determination of appropriate metrics and algorithms to be applied to basic acoustical measurement data to predict human response to sounds.

(5) A brief review of some of the relevant details concerning the topic of ultrasonic flaw detection is also included. Ultrasonic flaw detection represents a rapidly growing use of acoustical energy for the purposes of nondestructive testing. It is included because it exemplifies an active contemporary application of acoustical principles within our technology, and because it is a "measurement intensive" industry. There are numerous other applications for ultrasonic acoustic energy, one of which -- medical ultrasound for diagnostic and therapeutic purposes -- is described in another of the National Measurement System studies[1] in this series.

1.4. Limitations of the Study

For a number of reasons, there are several important activities in the field of acoustics which are not described in the present report and for which the relevant infrastructure of the National Measurement System has yet to be delineated. Notable among these are the fields of underwater acoustics, physical acoustics, and physiological acoustics.

Underwater acoustics is a relatively new activity within man's utilization of sound, since it has only been since the early years of this century that man has been able to make use of sounds for purposes of location, identification and communication underwater. Much of the technology is guided and used by the members of the international naval community. Some of the more advanced and sophisticated applications are classified. Because the resources available were too limited to adequately survey this complex and yet extremely active field of acoustics, a conscious decision to omit underwater acoustics from the scope of this study was made. However, within the U. S. Navy, integrated systems of reference measurement standards, performance standards, and standards laboratories are known to exist. In the future, it would be desirable to assess the relationship of this largely defense-oriented activity to the remainder of the National Measurement System for acoustics.

Physical acoustics has not been included within the scope of this study for several principal reasons. Initially, the scope of physical acoustics includes studies ranging from low temperature physics to the study of molecular processes in rarefied gases. In other words, the field is itself very extensive and measurements of acoustical quantities are often of secondary interest. Moreover, within the field the majority of measurement operations are conducted without concern for adherence to a "standard" measurement methodology (and in fact frequently none is appropriate), the interpretation of the acoustical data is of immediate concern only to isolated relevant researchers, and the relevance of the measurement to other acoustical measurement operations is often only peripheral, however basic the physical phenomenon.

Physiological acoustics, including the topic of hearing aid design, testing and fitting, is excluded principally because of a concern that the present report should direct attention principally to physical measurement processes, without the introduction of the complications attendant to biological mechanisms.

The scope of the present report, as has been indicated, has been principally restricted to those activities which are both motivated by increasing societal concern over noise and involve numerous acoustical measurements. However, other activities exist within acoustics which are not described in the present report. The findings of the recent "Conference on Acoustics and Societal Problems" [2] describe some of the additional activities. The interested reader is referred to the conference report for much relevant material.

2. STRUCTURE OF THE MEASUREMENT SYSTEM

2.1. Conceptual System

2.1.1. Quantities Being Measured

The principal physical quantity being determined when performing an acoustical measurement is that of the pressure fluctuation we term sound.

Perhaps the simplest property under study is the pressure amplitude. Acoustical signals are complicated time-varying phenomena, and it is not sufficient to make one measurement to determine the pressure amplitude. Rather, it is essential to determine some measure of the pressure amplitude involving averaging over an appropriate time period. Frequently, we seek to characterize the temporal root-mean-square (rms) pressure amplitude, with some appropriate time period over which the averaging operation may be performed.

The motivation for many acoustical measurements lies in a desire for quantitative estimation of some subjective response such as loudness, aversiveness, or annoyance which is derived from quantitative measurements of the acoustical signal. Therefore, it is not surprising that measurements are conducted with the explicit intention of obtaining the specific physical measurements which are most directly relevant to the estimation of subjective response. Three factors enter into immediate consideration when one sets out to characterize acoustic signals within the audible range.

1) The first has already been alluded to: the signals vary with time in a complex manner. It is necessary to obtain the rms pressure amplitude, averaged over some time period consistent with both the characteristics of human hearing and with the time scale over which the signal is relatively consistant in its characteristics.

2) Secondly, the range of pressure amplitudes which the human sense of hearing can meaningfully interpret without discomfort is a range of more than a million to one. Because of the extent of this range, and because many subjective reactions to changes in pressure vary approximately logarithmically with the pressure, it has become customary to specify pressure amplitudes by making use of a logarithmic measure of pressure amplitude. A frequent measure of an acoustic quantity is expressed in terms of a "sound-pressure-level (SPL)", which is expressed as follows:

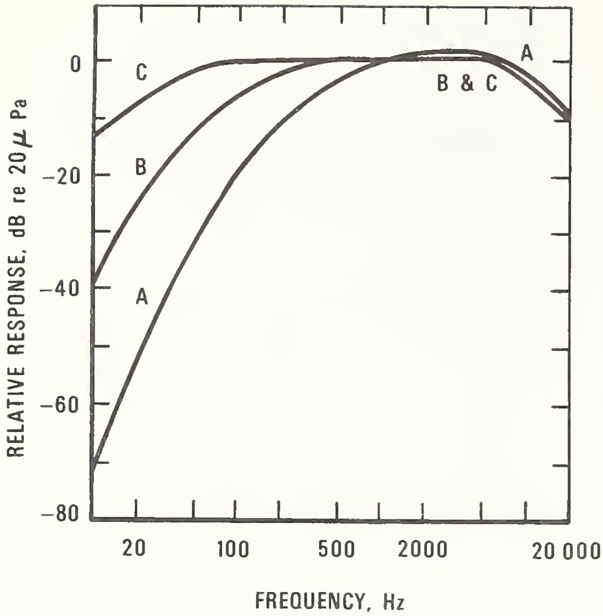
$$SPL = 10 \log_{10}\left(\frac{p_{rms}^2}{p_o^2}\right) =$$

$$20 \log_{10}\left(\frac{p_{rms}}{p_o}\right) \text{ dB re } p_o$$

where p_{rms} is the temporal root mean square (rms) sound pressure in pascals (Pa) and p_o is the rms reference sound pressure in pascals. The reference pressure, p_o, is equal to 20 μPa.

It is implicit in this measure that some appropriate time period be used to define the rms pressure amplitude p.

3) The third factor entering into characterization of acoustic signals lies in the realization that the human subjective response to sounds of equal pressure amplitude, but at different frequencies, is not linear. That is, the subjective loudness of a low frequency pressure fluctuation will generally be less than that for an otherwise comparable, mid-audible-range, signal. In order to account for this difference, numerous frequency-weighting curves have been developed over the years. The most commonly used is termed the A-weighting characteristic, and it approximately corresponds to the inverse of the 40-phon contour of the human ear. When one determines sound pressure level making use of a frequency-weighting characteristic in the measurement process, one is said to determine the "frequency-weighted sound level", such as the A-weighted sound level (see figure 1 for the internationally standardized weighting curves for sound level meters).



These considerations result in characterization of some of the more simply defined time-averaged and frequency-weighted characteristics of the complex pressure fluctuations. More complicated characterizations of such factors as peak amplitudes, statistical measures of sound levels, and of the temporal fluctuations are constantly being developed. However, the vast majority of measurements motivated by concern over noise fundamentally involve determination of sound pressure levels.

Because of interest in quantitative measures of the total acoustic emission from sources of environmental noise, it is frequently desirable to determine either the sound pressure level averaged over many positions at some reference distance from the source, or alternatively, the sound power which is inferred from measurements of sound pressure at prescribed distances and angular orientations and from certain properties of the acoustic field. The total acoustic power W emitted by a given source can be related to the mean squared pressure $\overline{p}^2$ under appropriate (far field) conditions by

$$W = \int_S \underline{I}(\underline{r})\cdot\underline{ds} = \int_S \frac{\overline{p^2(\underline{r})}}{\rho c} \cos\theta \, ds.$$

Thus the acoustic power can be inferred from measurements of squared rms pressure amplitude, determinations of the density e [kg/m^3] and velocity c [m/sec] of propagation in the medium, and from consideration of the area over which the pressure amplitude is approximately constant. These measurements are then related to the intensity of the acoustic field I9r) [W/m^2] and integrated over a surface S[m^2] enclosing the source to obtain the acoustic power [W] emitted by the source.

Characterization of environmental noise generally involves measures of both the temporal and spatial characteristics of environmental noise. Typically, one will either make use of statistical description of the temporal fluctuations in the acoustic field, or one will perform some process of temporal integration to obtain a measure of the total noise exposure that an occupant of the space in which the acoustic field exists has experienced. Procedures for adequate characterization of the spatial variations of sound pressure levels are the subject of current research, but typically, one might determine contours of equal sound pressure level throughout the space under study.

These considerations indicate the nature of the quantities being measured when one is principally interested in characterizing sound by describing its amplitude characteristics. However, there is considerable interest in describing the distribution of acoustical energy as a function of frequency. Thus there are many instrumentation elements and systems which permit one to obtain measures such as the sound pressure level contained in some prescribed frequency band, or the band pressure level. Typically, one makes use of octave band, one-third octave band, or constant percentage bandwidth filters and analysis schemes. Alternatively, constant bandwidth filters, such as one Hz or 100 Hz bandwidths, are used.

Many acoustical measurements are conducted to determine the acoustical properties of architectural materials and systems. In these measurements, the quantity being measured is the energy absorption or transmission properties of some material. These measurements are discussed more fully in Section 2.2.2.1.

Because man's concern with sound is related to his ability to hear and interpret sounds, it is natural that the quantitative measurement of this ability would be an appropriate subject for study. Indeed, the measurement of auditory acuity enables one to assess hearing impairment and to characterize appropriate acoustic signal processing or noise measurement methodologies. Characterization of auditory acuity is typically accomplished by determining the threshold of hearing, which is the lowest sound pressure level at which a subject just perceives a sound. By comparison with data characterizing the threshold for a large sample of the population with negligible impairment, it can be determined whether or not the individual's hearing threshold is "normal", or whether there is impairment.

Having established that one can quantitatively characterize sounds or noises by determination of the sound pressure levels or by means of the total acoustic power emitted, describe environmental noise, obtain quantitative measures of the acoustic properties of materials to be used in the implementation of noise control measures, and make quantitative measures of hearing acuity, there is still an additional element required in any discussion of acoustical measurements. This element is the consideration of the subjective reaction to various sounds. An important goal of psychoacoustical research is the evolution of algorithms from which one can predict human response to sounds from the physical measurement of the sound. The development of the algorithms is complicated, but in general involves subjecting experimental subjects to well characterized acoustic signals in order to determine corresponding quantitative measures of the subjective response. Research in psychoacoustics has led to the development of frequency weighting characteristics curves such as the A-weighting curve mentioned earlier in this section.

The preceding considerations have all dealt with quantitative measures motivated by or related to human perception of audible acoustic signals. For centuries the scope of acoustics was limited to the consideration of the pressure fluctuations which man could perceive as sound. However, as our technology has developed, we have learned to make use of acoustic signals with principal energy content orders of magnitude above the frequency band of human hearing, the so-called ultrasonic range. The principal uses of ultrasonics considered in this report are those involved in identifying the presence of cracks or voids within solid structures, termed ultrasonic non-destructive testing (USNDT), and in studying the acoustic emissions of stressed systems. Typically, an acoustic pulse is introduced into a solid structure under study, and the various reflections from boundaries of the structure or from the cracks or voids are studied. The simplest interpretation of the data suggests that one estimates the size of the crack or void from the amplitude of the reflected pulse. Inherent in these considerations is the understanding that large (relative to the acoustic wavelengths) flaws will have very large scattering cross sections with correspondingly large amplitudes for the reflected pulses. Acoustic emissions are studied in order to yield information about flaws which in turn portend failures.

2.1.2. Interrelationship of Quantities Being Measured

As the preceding section has indicated, the majority of noise-related acoustical measurements concern the determination of sound pressure level. This quantity is inferred from measurements conducted with regard to concern for appropriate (relatively short term) temporal averaging and frequency weighting procedures. Physically, however, the measurements concern the determination of pressure amplitude.

Concern over the quantitative characterization of the acoustic radiation averaged or integrated over all possible angles gives rise to determinations of the spatially averaged sound pressure level, or the total acoustic power radiated. To infer this latter quantity, it is necessary to determine the density of the acoustic medium and the velocity of sound in order to infer the intensity of the acoustic radiation averaged over some appropriate surface. This intensity is determined from an assumed relationship between pressure amplitude, density, and velocity of propagation. Integration of the intensity over the surface area yields the power radiated through the surface. Provided that the surface over which the measurements are obtained is properly sampled and that all of the energy radiated by the source passes through the surface, these measurements of pressure, density, velocity of sound, and area yield the radiated power.

Architectural acoustical materials are characterized by measures of their fractional acoustic energy absorption or transmission. These properties are inferred from measurements conducted in special test facilities. Either a change in rate of sound pressure level decay is determined (for absorption studies), or the sound pressure level is determined under circumstances in which a test structure serves as a transmitting element that separates a sound source from a well known acoustical system (for transmission loss studies). Once again, the central measurement process involves determination of sound pressure level, or of the rate of decay of sound pressure level.

The measurement processes concerned with both audiological and psychoacoustical measurements require the quantitative assessment of subjective response to a well specified acoustic signal. For audiological measurements, the subjective response is typically a relatively simple detection task; but for psychoacoustical purposes more complicated subjective responses are studied.

Ultrasonic flaw detection measurements are performed in order to locate and characterize flaws in a wide variety of specimens and materials. A related class of ultrasonic measurements, called acoustic emission measurements, are performed in order to provide information concerning failure-related phenomena such as crack propagation. In flaw detection measurements, time of propagation data are used to infer the location of flaws within the material under study, and measurements of the reflected signal amplitude sometimes are used to estimate the size of the flaw. In measurements of acoustic emissions, the amplitude of the emissions is thought to be related to the magnitude of the failure-related phenomenon.

2.1.3. Units Used in Acoustical Measurements

The principal acoustic measurements frequently are concerned with sound pressure levels, which are logarithmic measures of pressure amplitudes. The reference pressure (the weakest sound pressure perceived by the "average" person at 1000 Hz) used is 20×10^{-6} pascals. A sound pressure level near the threshold of feeling (tickling sensation) will be 120 dB corresponding to a pressure amplitude of 20 pascals.

The unit for characterization of acoustic power emissions is the watt. One watt of acoustic power is approximately the amount of power produced by one thousand people, each shouting as loudly as possible; i.e., an individual person can produce approximately one milliwatt by shouting.

Acoustical absorption is characterized by the energy absorption coefficient; e.g., an absorption coefficient of 0.95 implies that 95% of the incident energy is absorbed by the specimen. Total acoustic absorption is described in terms of the equivalent area over which all of the incident energy is totally absorbed; this quantity is given by the product of the surface area and the corresponding energy absorption coefficient.

The acoustic airborne sound transmission properties of building elements, such as partitions, are given in terms of a logarithmic measure of the energy transmission coefficient. That is, if 10% of the energy incident upon unit area of a partition is transmitted through and/or re-radiated by the partition, the transmission coefficient is 0.10, and the appropriate logarithmic measure of the transmission coefficient is given by the transmission loss (TL, where $TL = -10 \log (0.10)$ dB or TL = 10 dB in this case.

Somewhat more complex single-figure rating systems are used to summarize the frequency weighted absorption, transmission, and impact isolations or structure borne sound properties of architectural systems.

The majority of audiologic data are implicitly referred to the threshold of hearing of "normal" individuals and thus rely upon a reference data base. The units used to quantitatively assess departures from the normal threshold, however, frequently are those appropriate for sound pressure levels.

Psychoacoustical research has led to such a proliferation of related acoustical data processing algorithms to yield predictions of human response from physical measurements, that there are now more than 35 algorithms used (see table 1 and figure 2). Thus one finds the use of data involving 35 "units" throughout the literature, with wide disparities in the resultant predictions of subjective responses.

The units used for ultrasonic non-destructive testing are at present not precisely stated or directly traceable to fundamental physical processes. For example, in ultrasonic measurement systems used for material acceptance on the basis of internal flaw size, the measurements involve the use of reference blocks with artificial defects for system calibration. These

Table 1. Some physical and psychophysical units* for measuring noise.

Abbreviation	Name	A Typical Product Use
	PHYSICAL	
NBPL	Narrow Band Pressure Level	Gear Driven Apparatus
OBPL	Octave Band Pressure Level	Housing
SPL	Sound Pressure Level	All
TOBPL	Third-Octave Band Pressure Level	Transportation Equipment
	PSYCHOPHYSICAL	
AI	Articulation Index	Communications Equipment
CNR	Composite Noise Rating	Residential Dwellings
CR	Correction Factor	Offices and Factories
EAI	Effective Articulation Index	Communications Equipment
EPNL	Effective Perceived Noise Level	Aircraft
GPHON	Phon (GF)	Export Manufactures
GSONE	Sone (GF)	Export Manufactures
LL	Loudness Level	Radio and Television
LR	Level Rank	Offices and Factories
NEF	Noise Exposure Forecast	Aircraft
NNI	Noise and Number Index	Schools and Hospitals
NOY	Noy	Surface Vehicles
NPL	Noise Pollution Level	Schools and Hospitals
NR	Noise Rating	Residential Dwellings
OPHON	Phon (OD)	Appliances
OSONE	Sone (OD)	Appliances
PHR	Predicted Human Response	All
PNL	Perceived Noise Level	Surface Vehicles
PNLT	Tone Corrected PNL	Aircraft
SIL	Speech Interference Level	Office Equipment
SLA	A-weighted Sound Level	Highways
SLAS	Slow Response SLA	Construction Equipment
SLB	B-weighted Sound Level	Metal-working Equipment
SLC	C-weighted Sound Level	Farm Equipment
SLD	D-weighted Sound Level	Railcars
SLE	E-weighted Sound Level	Boats
TNI	Traffic Noise Index	Highways

*The definitions for most of these units can be found in the following source: About Sound (Office of Noise Abatement and Control, U. S. Environmental Protection Agency, Washington, D. C., May 1976).

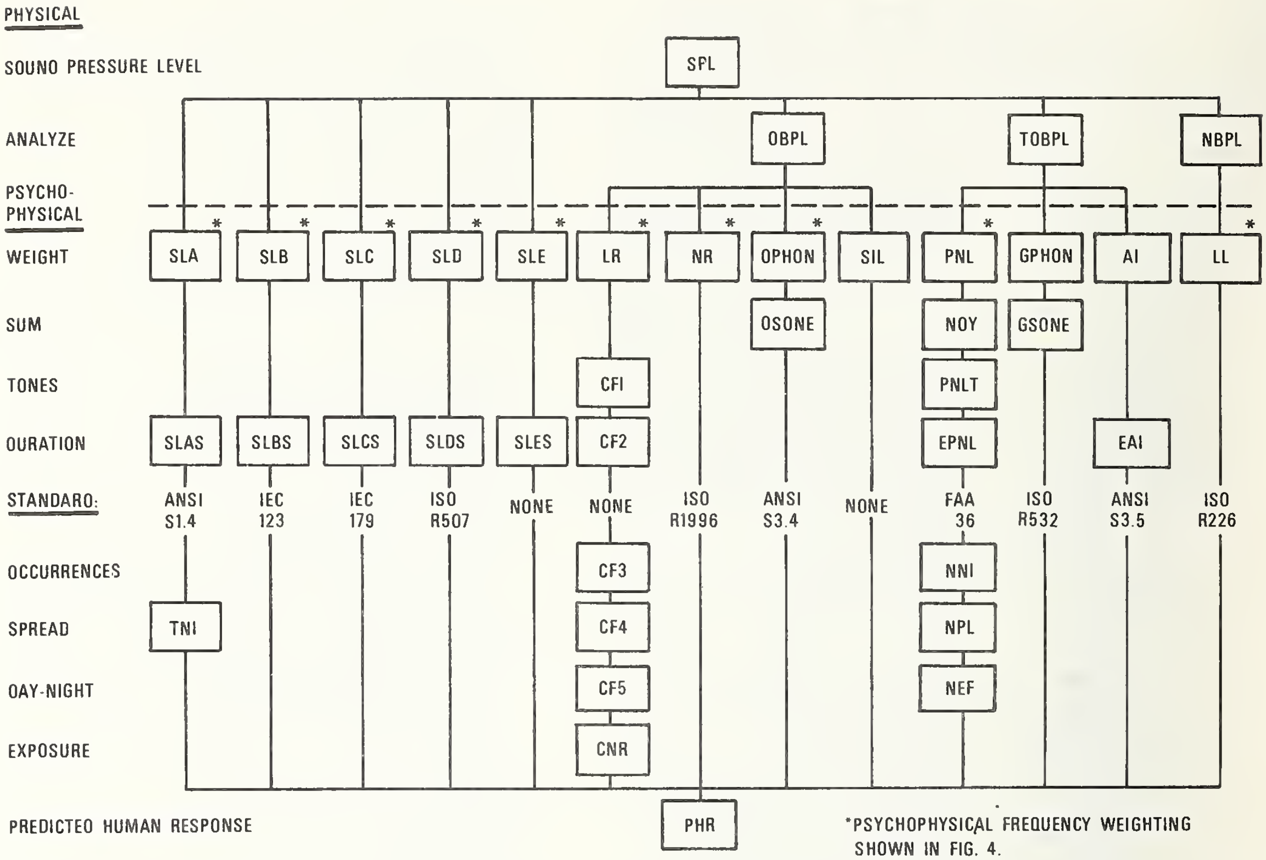


Figure 2. From sound pressure level (SPL) to predicted human response (PHR).

reference standards rely on inadequately precise primary reference and result in unacceptably large variations between nominally identical reference blocks. A well defined primary standard and a thorough understanding of the physical process of the measurement relating the measurand to basic SI units is needed. A proper dissemination system with clear feedback from the users also needs to be developed. In the area of ultrasonic acoustic emission measurements, the knowledge of the absolute sensitivity and the spectral response of acoustic emission transducers is of great importance. In state-of-the-art measurements an attempt is made to classify flaws which produce acoustic emissions based on signal strength. In attempts to improve the measurement system, researchers are presently investigating the spectra of the received signals to determine the nature of the source.

2.1.4. Derivation from SI Base Quantities

Microphones are calibrated by the reciprocity technique. The physics of the procedure are well established, and enable one to calibrate the microphone sensitivity [Volts/micropascal], from measurements of length [meter], static pressure [pascals], voltage [Volts], resistance [ohms], frequency [hertz], and the ratio of specific heats of the acoustic medium [dimensionless]. The relationship of these units to basic SI units is well developed.

The majority of acoustical measurement processes require that the properties of the acoustic field be determined by means of some electroacoustic transducer. This yields an electrical signal which is proportional to the acoustic pressure at the point at which the microphone is located. The microphone must be accurately calibrated in order that measurements of the properties of the electrical signal can be used to infer the analogous properties of the acoustic field.

2.1.5. Nature of the Physical Reference Standards

Few physical standards exist in acoustics. The principal phenomenon under study in most of the measurement procedures is the temporal average squared pressure fluctuation we term sound. A standard source of sound would therefore be, in principal, desirable. However, the stability of most sources of sound is not as high as would be desired for a standard source. There are two types of devices used for reference sound source purposes. The term "reference sound source" refers to a device constituting a source of sound for which the acoustic *power* output has been previously determined, or for which the power output characteristics of similar devices have been known. Several aerodynamic devices are currently available for use as reference sound sources and are often used as a source of comparative data in determining the acoustic power output of noise sources. A second type of device is used to produce a reference *sound pressure*, and is used for the purposes of field checks on the sensitivity of microphones. These devices are termed pistonphones or microphone calibrators, and are produced by several manufacturers.

2.2. Basic Technical Infrastructure

2.2.1. Documentary Specification System

2.2.1.1. Standardization Institutions

In the context of this report it should be clearly understood that there are several types of standards. So called "measurement methodology" standards deal with specification of techniques for physical measurements while other standards provide definitions of descriptive terminology. The class of standards referred to as engineering or industrial standards specify methods of test and document agreements on such parameters as dimensions, performance and physical characteristics for products that are specified, designed, manufactured and sold. Industrial standards usually include more specific types of standards termed product standards, commercial standards, and safety standards. The majority of these industrial standards are normally not a matter of law, and most of the relevant acoustical standards are developed in the private sector.

However, mandatory standards are issued by municipal, state and Federal governments in areas such as health and safety or pollution control and abatement. The incorporation of widely accepted standards, whether measurement methodology, descriptive terminology, or industrial standards into contracts, codes and regulations has the effect of rendering them mandatory.

The overall infrastructure of standardization institutions in the field of acoustics is shown in figure 3. In addition to those organizations shown, there is significant interaction with the mechanical shock and vibration infrastructure.

International standards dealing with instrumentation for acoustical measurements fall under the purview of International Electrotechnical Commission Technical Committee 29 on Electroacoustics (IEC/TC29). The U. S. Technical Advisory Group to IEC/TC29 consists of three related American National Standards Committees: S1 on Acoustics, S2 on Mechanical Shock and Vibration, and S3 on Bioacoustics. The Acoustical Society of America serves as Secretariat of S1, S2, and S3, and thus serves as liaison between technical experts and the American National Standards Institute.

International standards dealing with acoustical measurements (other than those directly concerned with instrumentation) are the responsibility of International Organization for Standardization Technical Committee 43 on Acoustics (ISO/TC43). There are two subcommittees under ISO/TC43 which work independently -- Subcommittee 1 on Noise (ISO/TC43/SC1) and Subcommittee 2 on Building Acoustics (ISO/TC43/SC2). American National Standards Committees S1 and S3 function as the U. S. Technical Advisory Group to ISO/TC43/SC1 and American Society for Testing and Materials Committee E-33 on Environmental Acoustics serves as U. S. Technical Advisor to the ISO/TC43/SC2.

Both IEC/TC29 and ISO/TC43 are active at present, particularly with regard to measurement standards needed in conjunction with the worldwide proliferation of noise regulations. The Commission of the European Communities ("Common Market") is becoming increasingly active in noise measurements and has established liaison with ISO/TC43/SC1.

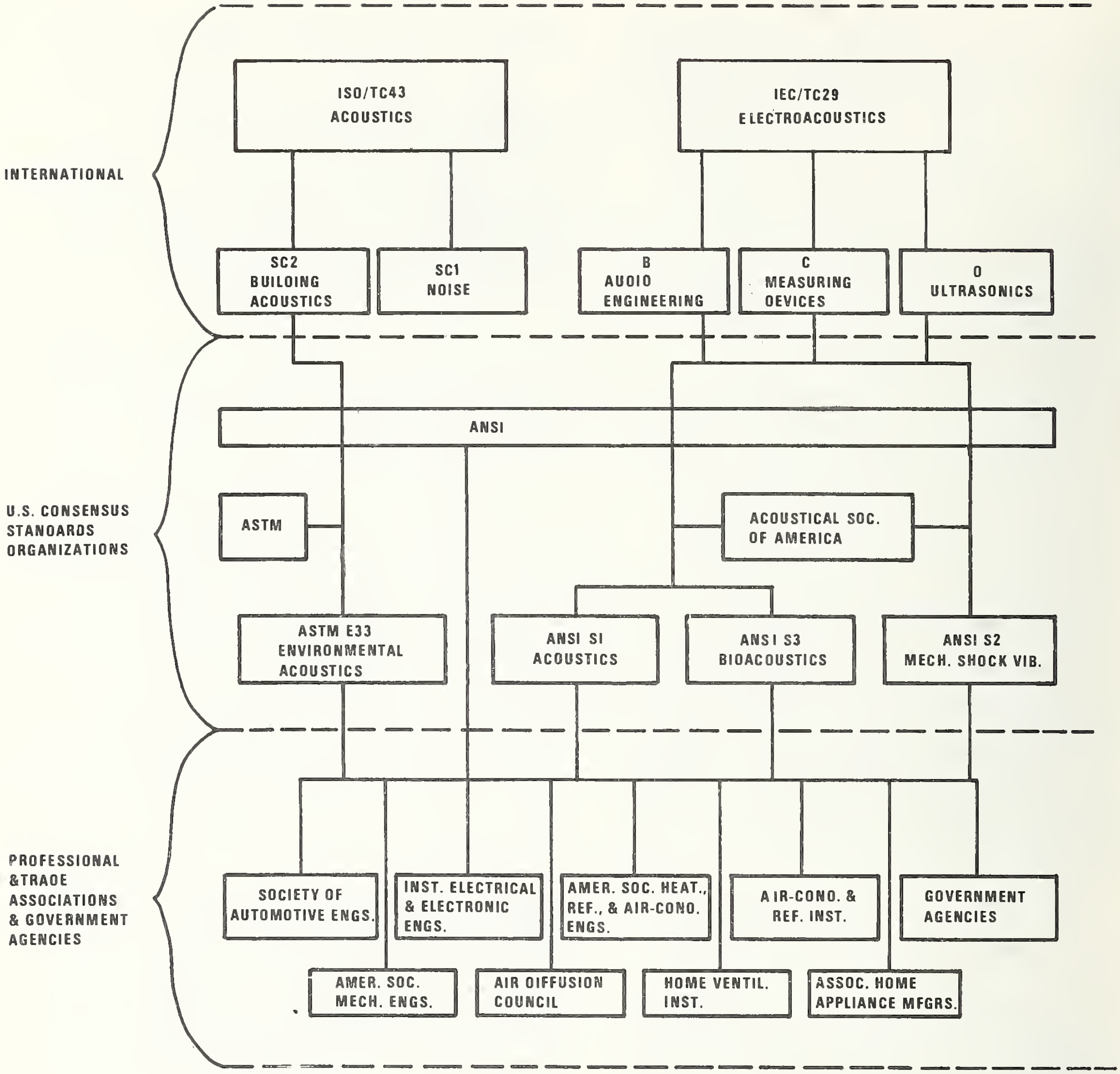


Figure 3. Infrastructure of standardization institutes in acoustics.

International activities concerning aircraft noise mainly are the concern of the International Civil Aviation Organization (ICAO) Committee on Aircraft Noise (CAN). United States liaison with ICAO is handled by the U. S. Department of Transportation.

Numerous Federal, state, and local agencies have promulgated noise regulations based on objective measurements. In some cases, these agencies have prescribed, or will prescribe in the future, measurement procedures. Federal agencies in this category include:

- o Environmental Protection Agency
- o Department of Transportation
- o Department of Labor
- o Department of the Interior

States and cities which have been particularly active in establishing quantitative noise regulations include California, Illinois, New York City, and Chicago. These Federal, state, and local agencies usually have very limited interaction with the standardization institutions shown in figure 3. Additional material on this topic can be found in Section 2.4.4.

The majority of broad, generic acoustical standards in the United States are produced by the three American National Standards Committees (S1, S2, S3) and by American Society for Testing and Materials Committee E-33. These committees follow well-established consensus procedures and thus, their standards reflect inputs from professional and trade associations, consumers, and government agencies. Many professional and trade associations (see figure 3) also produce their own acoustical standards, the most active organizations being the Society of Automotive Engineers, the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, and the Air-Conditioning and Refrigeration Institute. Some organizations (notably the American Society for Testing and Materials and the Society of Automotive Engineers) submit their acoustic standards for approval by the American National Standards Institute.

There is a limited number of Federal specifications dealing with acoustical materials. However, the Department of Defense and the General Services Administration now more frequently require Federally purchased items to meet prescribed specifications concerning their acoustic performance than in the past. For the most part, these agencies do not issue new measurement procedures but rely on existing standards. The Department of Housing and Urban Development and the Department of Transportation have established policies concerning the noise levels (at a prospective building site or along a highway) which must not be exceeded to qualify for Federal financial assistance. These policies spell out the required measurement procedure.

Overall, the large number of noise regulations and noise-related contractual arrangements in recent years has dramatically increased acoustic standardization activities. The standards community is preparing for this work and a trend toward national and international harmonization is becoming evident.

2.2.1.2. Survey of Documentary Standards

The Noise Control Act of 1972 (PL 92-574) gave the U. S. Environmental Protection Agency a wide range of authority for the establishment of noise emission standards for products, regulations on products intended to reduce the noise of related products, and for the coordination of related research and noise control in the Federal agencies. This Act specifically calls for NBS-EPA cooperation in regard to research and development of improved methods and standards for the measurement and monitoring of noise.

In cooperative work undertaken prior to the enactment of this legislation, NBS prepared a compilation of more than 200 acoustic standards that are believed to be specifically relevant to noise control and abatement. NBS Special Publication 386 "Standards on Noise Measurements, Rating Schemes, and Definitions: A Compilation" [4] provides this information.

The publication presents material assembled from the various standards, industrial and trade organizations, and from the relevant technical and scientific societies concerned with acoustics. No attempt has been made to review or to critically evaluate the standards, although a serious attempt has been made to include in the listing all those standards that are available and relevant. Because of the broad range of topics in acoustics, the standards cover a broad scope including:

--- measurement techniques and instrumentation

--- rating schemes

--- definitions

--- equipment and product specifications

--- subjective measurements and response to noise

--- calibration methods.

The compilation includes paragraphs describing the standards and giving a brief summary of the intent and/or scope of each standard. In some cases the text is drawn from the official description of the standard as issued, while in others the spirit of the standard is described. An Appendix lists the names and addresses of the various organizations or societies and their acoustical standards committees. All information available as of January 1, 1976, is included.

Because of the lack of central coordination in standards writing activities of the United States, there are numerous identifiable deficiencies in the organization, structure, and interconsistency of the relevant acoustical standards.

Some shortcomings of the nation's acoustical standardization system have come into prominence as a consequence of attention to the issues of:

--- consumer/workplace safety

--- environmental pollution control

--- barriers to international trade.

A number of recent legislative actions in response to these issues give impetus and a sense of urgency to the development of standards and measurement methods that are needed for the effective implementation of national programs on noise abatement and control. The laws that have been enacted rarely call specifically for new or improved measurement standards, yet they require them implicitly. The sense in which they are implicitly required is that the enforcement of these regulations must be based upon uniform and equitable measurement methodology in order to maintain economic equitability among the affected groups (often manufacturers).

In the technology of ultrasonic nondestructive testing, Technical Committee E-7 of the American Society for Testing and Materials has produced several methods of test and recommended practices covering a wide range of ultrasonic testing. These include the evaluation of testing systems [5], fabrication and checking standard reference blocks [6, 7] and methods of inspection for structures and products [8].

2.2.2. Instrumentation System

2.2.2.1. Measurement Tools and Techniques

Most sound-measuring devices are designed to respond either to sound pressure or to particle motion. Of the two quantities, sound *pressure* is easier to measure accurately over a wide range of frequencies and amplitudes. Hence, measurement of pressure is much more prevalent than that of velocity. Thus, almost all instruments for the accurate measurement of sound employ transducer elements which respond to sound pressure. Such an element is commonly referred to as a pressure microphone. Its purpose is to transform acoustical energy into electrical energy.

In order that we might properly infer the corresponding properties of the acoustic signals from the electrical signal provided by the microphone, it is essential that the calibration of a microphone be accurately known. Calibration is accomplished by means of the reciprocity technique (developed at the National Bureau of Standards), and is described fully in American National Standard Method for Calibration of Microphones, S1.10-1966 [9]. This calibration process provides the electrical output of the microphone [volts] in response to some specified pressure fluctuation [micropascals], and is an important implicit factor in most acoustical measurements.

Instrumentation systems for noise measurements perform the following measurement and signal processing operations. The sound pressure is converted into an electrical signal by a microphone. This signal is amplified and passed through a filter which weights the various frequency components of the signal. The filtered ac signal is then detected (usually converted to a root-mean-square dc) and averaged over an appropriate time interval. This detected signal is then either displayed via some read-out device, or recorded on a magnetic tape recorder and brought back to the laboratory for analysis.

A device has evolved called a sound level meter, which is a relatively simple self-contained instrumentation system. Its main use is to measure sound pressure levels in air. A sound level meter consists of a microphone to transduce the sound into an electrical signal, an amplifier to raise the microphone output to a useful level, a calibrated attenuator to adapt the instrumentation to the sound level being measured, an indicating instrument exhibiting the measured sound level, weightings (A-, B-, and C-) to adjust the frequency characteristic of the response, and an output connection to accommodate additional measuring equipment.

Sound level meters usually are manufactured to the specifications contained in one or more of the following documents:

- International Electrotechnical Commission Recommendation on Precision Sound Level Meters, Publication 179 (1973) [10].

- American National Standard Specification for Sound Level Meters, S1.4-1971 [11].

- International Electrotechnical Commission Recommendation for Sound Level Meters, Publication 123 (1961) [3].

International Electrotechnical Commission Publication 179 (1973) gives tolerances for all three weighting networks. American National Standard S1.4-1971 defines several types, or classes, of sound level meter with different tolerances. Because of diverse precision and accuracy requirements for different applications, four types of sound level meters are specified: Type 1 -- Precision, Type 2 -- General Purpose, Type 3-- Survey, and Type S -- Special Purpose, with different tolerances for the Type 1, 2, and 3 instruments. American National Standard S1.4-1971 specifies a number of additional characteristics of sound level meters, including dynamic range, directional response, and sensitivity to various environmental conditions. Of particular importance is the detector circuit, which should provide true root-mean-square response to signals of different crest factors and provide appropriate averaging times corresponding to the specified "fast" and "slow" dynamic characteristics. The American National Standard Type 1 tolerances are essentially identical to the International Electrotechnical Commission tolerances except below 100 Hz where the American National Standard Tolerances are tighter. If direct measurements are to be made of the A-, B-, or C-weighted sound level, the allowable tolerances on the frequency weighting should be clearly referenced to one of the above standards.

In acoustical measurements where a frequency analysis is required, it has been traditional to use a bank of contiguous band-pass filters, and to switch through them sequentially to obtain the sound pressure in each frequency band. More recently, real-time analyzers have become available which have parallel filters, with detection and read-out for each frequency band. Alternatively, the instantaneous voltage from the microphone can be passed through an analog-to-digital converter which is interfaced to a computer. Filtering and detection are done digitally within the computer.

A complicating factor relevant to the preparation of measurement methodology standards is the fact that the measurement standard should not assume any particular instrumentation configuration. Yet discussion of instrumentation performance specifications cannot be neglected or omitted, although the principal concern of the measurement standard is most properly with overall system performance, and not that of individual system elements.

It is the authors' judgment that frequency analyses required for regulatory actions will not generally require measurements in frequency bands narrower than octave or one-third octave bands. The International Electrotechnical Commission Standard on Octave, Half-Octave, and Third-Octave Band Filters Intended for the Analysis of Sounds and Vibrations, Publication 225 (1966) [12], defines the center frequencies and sets limits on terminating impedances, effective bandwidth, attenuation in the pass-band, attenuation outside the pass-band, overall tolerances, harmonic distortion, and the effects due to environmental conditions. American National Standard Specification for Octave, Half-Octave, and Third-Octave Band Filters Sets, S1.11-1966 [13], is a rather more detailed document which establishes three classes of band filters, Classes I and II for octave band filters and Classes II and III for half-octave and one-third- octave band filters.

The choice of a filter for a given measurement is based upon the accuracy required. The bandwidth error of a filter depends upon its transmission loss at the band edges, the slope of the transmission loss characteristic outside the band, and the input noise spectrum slope. Appendix B of American National Standard S1.11-1966 discusses the subject and gives data and references allowing selection of filter characteristics which will yield measurements falling within specified error limits at various noise spectrum slopes.

The electrical signal from a microphone is typically comprised of the sum of components at many frequencies. The measuring instrumentation should "detect" the root-mean-square value of this signal, averaged over the desired time interval. The International Electrotechnical Commission Standard on Precision Sound Level Meters, Publication 179 (1973), requires that instrumentation complying with that standard be able to measure the combination of signals of two non-harmonic frequencies to within ± 0.1 dB of the true rms value.

Although noise measurement instrumentation with different principles of operation may be calibrated to yield the same results on steady-state signals, such may not be the case for transient signals such as motor vehicle pass-bys. It is recommended that measurement standards for sources which produce transient sounds include specific criteria for system response to one or more well-defined transient events (e.g., a pure tone that is amplitude- modulated in a specified manner).

Generally speaking, the primary function of acoustical materials in noise control is to impede the undesirable effects of sound reflection. Architects rely heavily on the use of acoustical materials. Such materials are rated over a range of frequency according to their acoustical absorptivity. The two most prevalent methods for measuring the sound absorption coefficients of acoustical, architectural or building materials are the reverberation room method[14] and the impedance tube method[15].

The reverberation room method for measuring the sound absorption coefficient of a test specimen is determined by measuring the change in the rate of decay of sound in a reverberation room when a test specimen is brought into it. In a routine test, a test specimen is placed centrally on the floor of the room. A test signal is turned on long enough for the sound pressure level to reach a steady state level in the room. The signal is then turned off and the time it takes the signal to decay to some prescribed level is measured. The absorption, A, (m^2), of the room and its contents is calculated from the Sabine equation

$$A = \frac{0.9210\ Vd}{c}$$

where: V = volume of the room, m^3
d = rate of decay, sec.
d = speed of sound, m/sec.

The decay time measured with the specimen in the room is then compared with that obtained when the room is empty. The difference in the decay times is a function of the sound absorption of the test specimen.

The impedance tube method for measuring the sound absorption coefficient of a test specimen is determined by measuring the difference between the maximum and minimum sound pressure levels in a standing wave set up within an impedance tube. Acoustic waves from a source are reflected by the test specimen and combine with the incident waves to form a standing wave pattern along the tube. This pattern is explored with a movable microphone to locate and measure the maximum and minimum sound levels. The difference between these two pressure levels is a measure of the sound absorption of the test specimen.

Of the two, the reverberation room method is the most widely accepted method for conducting such measurements.

In both of these measurement processes, the parameter of interest is the dimensionless fraction of incident energy which is absorbed by the test specimen. This parameter is inferred from measurements of pressure (for the tube method) and from measurements of pressure and the time rate of squared pressure decay (for the reverberation room method).

Acoustic energy transmission occurs in one or more of three principal manners: (1) as airborne sound transmitted along continuous air paths (2) as structure-borne sound which typically originates from direct impulses (e.g., footsteps) or direct mechanical contact between vibrating machinery and the building elements or (3) a combination of both (e.g., the sound from a power lawnmower causing a window to vibrate and radiate acoustic energy into a room).

In the case of airborne sound transmission, there are several highly specialized testing methods for the evaluation of the acoustic transmission properties of such building elements as ventilation ducts or mufflers. These test methods tend to become specially adapted to the particular requirements of the specific industry concerned, and in general are given in terms of measures of the dimensionless pressure ratios at specified positions.

For the case of structure-borne sound transmission, since mechanical energy can propagate as flexural or compressional waves within diverse structural elements, the tools and test methods are potentially complex. In fact, only one generally accepted test method dealing with the measurement of structure-borne sound has been adopted to any significant extent within this country. This test method deals with the assessment of the sound emitted into a room when the floor of the superjacent space is mechanically excited by a standardized form of impact excitation.

Since the data tend to be strongly varying functions of frequency, they are often further classified by making use of a specific frequency weighted curve-fitting procedure to yield a single number rating called an Impact Insulation Class (IIC). This single number rating is taken to be more or less indicative of the frequency-averaged impact response and structure-borne transmission properties of the floor-ceiling assembly.

The most common form of transmission of acoustic energy through structures, however, is the case of airborne sound transmission involving the mechanical vibration of a structural element. The measurement process involves determination of the difference between the space-time average sound pressure levels in two reverberation rooms separated by a wall containing a test panel under study. Following a simple normalization process, this measurement yields a measure of the fractional portion of the energy incident upon the panel which is transmitted into the adjacent space through the panel [16,17].

As in the case for direct mechanical (impact) excitation, the data are subsequently used in a frequency weighted curve-fitting procedure to obtain a single number rating called the Sound Transmission Class (STC). This rating, which can be used for comparing wall or floor specimens for general building purposes, is designed to correlate with subjective impressions of the sound insulation provided against the sounds of noise in buildings [18].

A description of the tools and techniques used to determine the threshold of normal hearing is presented in Section 2.2.3. In this section it should suffice to note that the principal tool is the audiometer, which consists mainly of an audio oscillator or noise generator and filters, an attenuator, appropriate amplifiers, and one or two earphones.

Mainly, we hear by conduction of sound by air. However, if a small vibrator is placed on the skull, sound is conducted by the bones of the head to the inner ear. A person with a middle ear difficulty could show an impaired hearing level by air conduction, but have normal hearing by bone conduction. Physicians use this difference between hearing by bone or air as a diagnostic tool. However, there are no standard reference threshold data for hearing by bone conduction and a standard procedure for calibrating the bone vibrators has just begun to be developed.

There are several methods frequently conflicting for adjusting physical measurements so as to reflect the human response to environmental noise. Some of these methods are embodied in domestic regulations and national and international standards.

After a measurement of the physical sound pressure level has been made, there are two major ways to process the data to yield adjusted data predicting the response of a person to the sound. First, a single weighting network characteristic of the simplified human response may be applied to the frequency components of the sound as measured on a sound level meter. Second, the sound may be frequency analyzed into several band pressure levels by a frequency analyzer. From the resultant frequency distributions more complex measures of the human response may be computed. The names of four physical units and 35 psychophysical units are given in table 1. The relationships among the various psychophysical units designed to reflect the Predicted Human Response (PHR) are depicted in figure 2. Each block in the diagram represents the name of a different unit for measuring the physical sound or for predicting the psychological response to that sound.

Many of these procedures for adjusting physical measurements of sounds so as to reflect the human response are based upon data collected by the paired-comparison method. In paired-comparison experiments human listeners are asked to compare two different sounds and report which one is judged "louder", "noisier", "more unpleasant", "more unacceptable", etc. By collecting judgements on many pairs of sounds it is possible to elaborate "equal loudness contours", "equal noisiness contours", etc., depending upon the verbal descriptor used to define the listener's response.

For example, if the single weighting network is used, a set of frequency weights proportional to the simplified human response is applied directly to the sound pressure level measurement. As can be seen in figure 2, five different sets of weights may be applied, producing the A-, B-, C-, D-, and E-weighted sound level.

The ten psychophysical units designated by asterisks in figure 2 are plotted in figure 4. Inspection of the figure reveals that the axes embrace the entire range of audible acoustic frequencies (20 Hz-20 kHz) and most of the range of audible acoustic intensities -- from the threshold of hearing (about 0 dB) to the roar of a jet takeoff (about 120 dB). If one assumes that the human perception of acoustic frequency and intensity is roughly logarithmic, then the disputed area where the ten frequency weighting contours disagree could represent from 10-20 percent of the total decibel measurement above the threshold of hearing (International Organization for Standardization R389 [19]). For the 90 dB level shown in figure 4, this discrepancy would be ± 15 dB.

The measurement tools and techniques used to perform ultrasonic non-destructive testing are rather different from the ones previously discussed. Frequently, the objective of a non-destructive test measurement operation is to identify the presence of an internal flaw such as a void or crack within a solid. The principal measurement tool used to accomplish this identification is termed an ultrasonic flaw detector, and it consists of an electronic pulse generator, a receiving amplifier, a gate system used either to protect the receiver from the energy developed by the pulse generator or to enable attention to be directed to some specific temporal portion of the received signal, and a cathode-ray-tube display. The output of the pulse generator is applied to a piezoelectric transducer, which generates a pulsed acoustic signal within the test specimen. Reflections of the pulse generate electrical signals in the receiving transducer which are subsequently amplified and displayed on the display tube. From the amplitude of the reflected signal the size of the flaw and its location can be estimated.

The process of flaw detection and identification is also aided by the fact that the amplitude of the reflected signal is affected by the inherent acoustic losses within the material under study, and by the physical size (deduced from the scattering cross section) of the flaw. Because the technology is oriented toward empirical solutions of measurement problems, and because the technology is also heavily interrelated with metallurgy, the means of system calibration commonly used makes use of sets of "reference standards". Here the term is used to denote right circular cylinders of varying diameters and lengths, with flat bottomed holes of varying diameters, used for the purpose of providing apparent man-made flaws of known geometry and location. These reference standards are artifacts used for the purposes of system calibration. Test specifications will typically require that the instrumentation be capable of identifying a 3/64" hole in a 4" thick block of aluminum, steel, or titanium. Because of the empirical nature of the technology, complete sets of reference standard blocks typically include three hole diameters in each of 19 standard thicknesses (a "distance amplitude" set) plus another set of eight hole diameters in one standard thickness (an area-amplitude set). These artifacts become an important part of the instrumentation system.

It is instructive to consider the types of instrumentation required for the performance of typical acoustical measurements. At least seven categories can be defined, as listed in table 2. A further breakdown of specific instruments and instrumentation systems typically contained within these seven categories is presented in table 3.

Products listed in the first two categories enable the measurement of an acoustical or related structural vibration

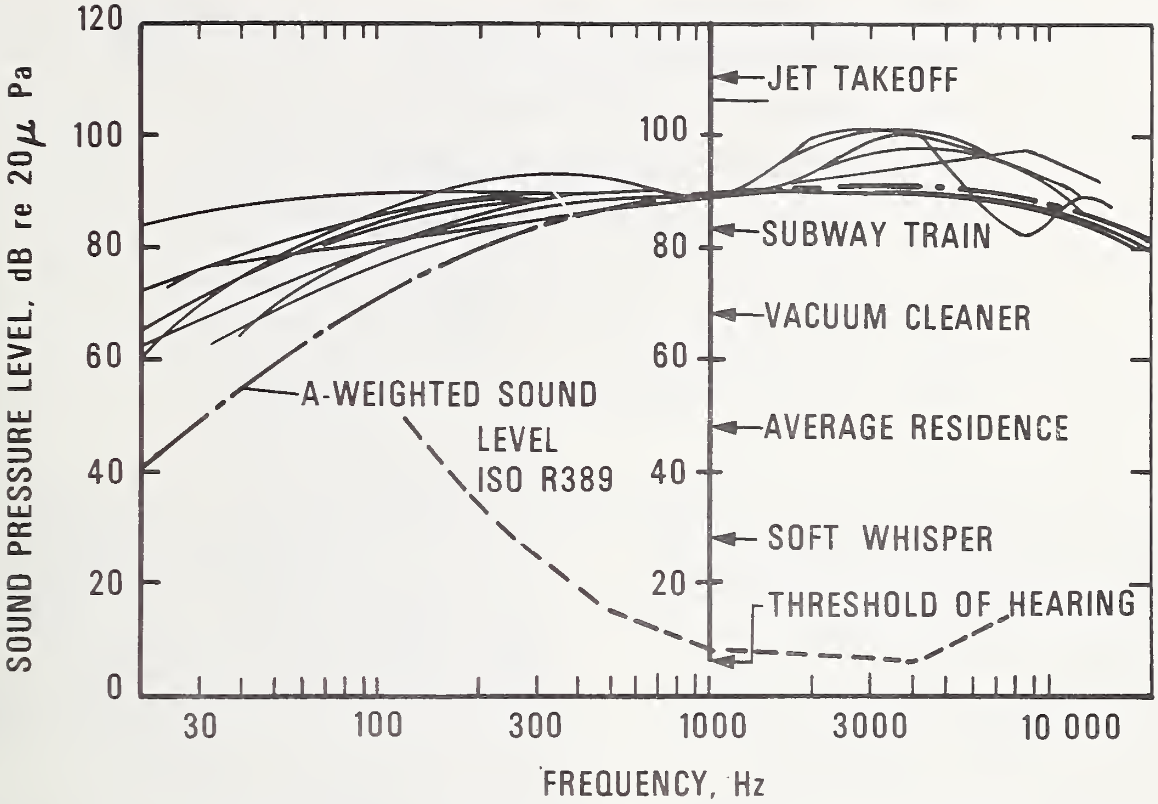


Figure 4. Ten different psychophysical units normalized to values at 1000 Hz.

property by measurement of analogous properties of an electric signal. That is, the transducers develop electrical signals which allow one to infer the corresponding acoustical or vibrational information from measurement of the properties of the electrical analog signal. The third category lists the instruments and instrumentation systems used to quantitatively characterize noise emissions or environments. The fourth category lists representative general purpose electronic instrumentation used to obtain appropriate inferences from measurements of the electrical analog signals. The more specific audio signal processing and analysis instrumentation elements are listed in the fifth category. The sixth category lists special purpose acoustical instrumentation produced for research or special purposes. The seventh category refers to those specific instrumentation elements required to apply acoustical measurements to the technology of ultrasonic non-destructive testing and evaluation.

2.2.2.2. The Instrumentation Industry

As noted earlier, the instrumentation required for the performance of acoustical measurements is widely varied. This is largely a consequence of the interdisciplinary nature of acoustics, and because a large number of related physical phenomena are of interest. The instrumentation industry involves a large number of manufacturers of related instrumentation, instrumentation systems, and materials and systems for the purposes of noise and vibration control. Four reasonably distinct categories emerge.

1. Instrumentation for Dynamic Measurements

2. Hearing Conservation Equipment

3. Materials for Noise and Vibration Abatement

4. Systems for Noise and Vibration Abatement

Table 2. Instrumentation required for acoustical measurements.

I.	Microphones and Related Accessories
II.	Vibration Transducers and Related Accessories
III.	Sound Level Meters, Noise Exposure Monitors, etc.
IV.	General Purpose Electronic Instrumentation
V.	Audio Signal Processing and Analysis Instrumentation
VI.	Special Purpose Acoustical Instrumentation
VII.	Ultrasonic Non-Destructive Testing Instrumentation

Of these four categories, the first two contain instrumentation of the types listed in tables 2 and 3, supplemented by products specifically intended for the implementation of hearing conservation programs. The other two categories contain listings of manufacturers of instrumentation intended for the implementation of noise abatement surveys or programs, supplemented by products required for the absorption of acoustical or vibrational energy. Collectively, the suppliers (for which a current listing is given in S)V Sound and Vibration [20] annually) represent the major sources of instrumentation and noise-control oriented materials and systems at the present time.

Although there are numerous manufacturers and suppliers of instrumentation intended for acoustical measurements, the majority do not supply products included in all of the categories. Two manufacturers, however, do have such an extensive acoustical instrumentation product line that their products are found in nearly all acoustical laboratories. One of these is a Danish manufacturer, whose products are marketed in the United States through an affiliate. The other is an American firm.

An adequate estimate of the economic magnitude of the instrumentation industry producing and/or marketing the required acoustical measurement instrumentation is not at present available. Currently, only scattered, fragmented estimates of various economic factors are available, and additional study by trained economists is necessary. Some of these factors are indicated in Section 4.3.1.

There is not sufficient economic data available at the present time to permit estimates of the relative importance of imports vs exports of acoustical measurement instrumentation. There is, however, some indication that there are appreciable exports of audiometric instrumentation [21] and of sophisticated digital systems for the accomplishment of fast Fourier transform and narrow band analysis. Eighteen of twenty-three known major manufacturers of audiometers are located in the United States.

Because of the absence of reference standards or artifacts in acoustical measurements, measurements made with the products of the acoustics instrumentation industry are only rarely traceable to reference standards. In the United States, at the present time, perhaps the only "traceable" factor in the measurement process may be that of the calibration of the microphone or accelerometer used to obtain the analog signal from which the acoustical properties are inferred. The calibration services of NBS are often cited as a "traceable" factor in these measurements, despite the fact that the traceability may be rather remote. For example, a microphone may not be directly calibrated at NBS, but rather it is calibrated using another microphone which has been calibrated at NBS. Details of these services are presented in Sections 4.2. and 4.3. of this report.

2.2.3. Reference Data

Data pertaining to the determination of the threshold of hearing, and to performance data on architectural acoustical materials

Table 3. Specific instrumentation required for acoustical measurements.

I. Microphones and Related Accessories

Condenser Microphone Cartridges
Electret Microphone Cartridges
Piezoelectric Microphone Cartridges
Preamplifiers/Signal Conditioners/Power Supplies
Pistonphone Calibrators
Sound Level Calibrators
Reciprocity Calibration Apparatus
Electrostatic Actuators
Windscreens
... Spherical (Cloth and/or Polyfoam)
.... Nosecones
Random Incidence Correctors
Directional Microphone Accessories
... Line Microphone or "Shotgun" Units
... Parabolic Reflectors
Probe Tubes
Outdoor Microphones
... Dehumidifiers
... Bird Repellant Adapters
Carrier/Multiplexer Units
Hydrophones and Hydrophone Arrays

II. Vibration Transducers and Accessories

Accelerometers
Velocity Transducers
Force Gauges
Mechanical Impedance Heads
Displacement Transducers/Instruments
... Mechanical
... Capacitative
... Optical
... Stroboscopic Devices
Preamplifiers/Signal Conditioners
... Charge Amplifiers
... Voltage Amplifiers
... Integrators
Vibration Meters
Vibration Severity Meters
Accelerometer Calibrators
Vibration Transducer Mounting Hardware

III. Sound Level Meters, Noise Exposure Monitors, etc.

General Purpose Sound Level Meters
Precision Sound Level Meters
Impulse Precision Sound Level Meters
Noise Dose Meters/Noise Dosimeter/Noise Exposure Meters
... Personal Units
... "Readers" or Monitors
... Monitor Devices for Fixed Installations
Noise Limit Indicators
Noise Exposure Statistical Distribution Analyzers

IV. General Purpose Electronic Instrumentation

Voltmeters
Logarithmic Voltmeter Converters
Low Noise Audio Frequency Measuring Amplifiers

Phasemeters
Oscilloscopes/Oscillographic Recorders/Graphic Level Recorders
Analog Magnetic Tape Recorders
... Instrumentation Type (FM and Direct)
... Audio Type
Digital Event and Transient Recorders
Delay Lines
... Digital
... Analog

V. Audio Signal Processing and Analysis Instrumentation

Audio Frequency Oscillators
Heterodyne Slave ("Tracking") Filters
Tracking Frequency Multipliers
Heterodyne Analyzers
Constant-Percentage-Bandwidth Frequency Analyzers
Third-Octave Band and Octave Band Audio Frequency Analyzers
Real Time Third-Octave Analyzers
Real Time Narrow Band Analyzers
Digital Signal Processing Instrumentation
... Fast Fourier Transform/Narrow Band Analysis Systems
... Signal Correlation Systems
... Computer Interfaces and Peripherals

VI. Special Purpose Acoustical Instrumentation

Reference Sound Sources
... Aerodynamic
... Loudspeakers/Omnidirectional Sound Sources
Standing Wave Tube Apparatus
Reverberation Processors
Tapping Machine
Vibration Generators/Exciters
Vibration Exciter Control Devices/Compressors
Artificial Ears
Artificial Mastoids
Artificial Voice
Audiometers
Audiometric Earphones
Audiometric Earphone Couplers
Audiometer Calibrators
Audiometer Booths/"Quiet Rooms"

VII. Ultrasonic Non-destructive Testing Instrumentation

Ultrasonic Flaw Detector
... Search Unit: Surface wave; contact
... Search Unit: Longitudinal wave; immersion
... Angle Beam: Contact or Immersion
Couplant medium
Test Specimen/Transducer Manipulation System
Immersion Tank
Reference Standards
Acoustic Emission Amplifiers
Acoustic Emission Signal Processor*
... Discriminator Module
... Event Counter Module
... Event Count Ratio Module
... Linear Emission Rate Module
... Log Emission Rate Module

*Acoustic Emission is a relatively new field, and the terminology is not standardized.

constitute most of the formal acoustical reference data.

The zero hearing threshold level, corresponding to normal hearing in the population, was obtained from measurements of the threshold of hearing (in volts) of large numbers of young adults. Results were usually presented in terms of a median earphone voltage. However, since earphone response could change over time, it was decided to retain threshold information in terms of sound pressure. Accordingly the earphone was placed on an artificial ear, or coupler (developed at NBS and called the NBS 9-A coupler), the voltage corresponding to threshold applied and the sound pressure in the coupler measured. This procedure was repeated at each frequency of interest, thereby obtaining a set of reference threshold sound pressures.

Since the coupler is not an exact acoustic duplicate of the human ear the sound pressure produced by an earphone is not the same in the coupler as it is in the ear. Furthermore, while threshold pressure in the human ear is presumably independent of the earphone used, the reference pressures generated in the 9-A coupler are found to be different for each earphone type. Thus, in this country, a set of data corresponding to the sound pressures generated in the NBS 9-A coupler, is recorded. For each earphone type the applied voltage is that which corresponds to the threshold of hearing. Thus, the coupler pressure data correspond to the threshold of hearing. Each time a new earphone type is designed and manufactured for audiometry, one has to perform a loudness-balancing procedure with the new earphone versus a standard earphone to establish new reference pressures. These reference pressure data then constitute the basis of the corresponding threshold data [22,23].

Other earphones and artificial ears are used in other countries. International Organization for Standardization Recommendation R389, Acoustics Standard Reference Zero for the Calibration of Audiometers, expresses threshold of hearing or the reference zero of the audiometer in terms of five national standard earphone-coupler combinations and their sets of reference equivalent sound pressure levels, made equivalent by a ring-around loudness balancing suggested by NBS [22].

These data, defining the reference zero or threshold of hearing, are then subsequently used to provide quantitative measures of hearing impairment. Thus the data are implicitly used whenever an audiometric examination is conducted. Explicit use of the data is principally confined to the members of standards committees and to the manufacturers of audiometric equipment.

The Acoustical and Insulating Materials Association, a national trade organization of manufacturers of a wide range of acoustical and insulating materials, annually publishes a bulletin containing performance data on architectural acoustical materials. These commercial data describe the acoustical properties of currently available material. These bulletins contain tabulations of data including sound absorption coefficients and sound transmission class information. These reference data are intended for use in the practice of architectural acoustics and noise control engineering, and derive from tests conducted in independent testing laboratories and in manufacturer's laboratories.

2.2.4. Reference Materials

There are very few identifiable reference acoustical materials. This was not always the case, and there have been, at various times, various suggestions for the use of acoustical reference materials. Many people are aware of things such as the use of tuning forks or pitch (frequency) standards, which of course to this day remain relatively common in music.

One of the more interesting uses of "reference materials" in architectural acoustics was made during the researches of W. C. Sabine [24]. Sabine realized that the decay times in the lecture room at Fogg Art Museum at Harvard University were inversely proportional to the total acoustical absorption, and that the total acoustical absorption could be measured in terms of the number of running feet of velour upholstered seat cushions taken from nearby Sanders Theatre. Thus, for a brief time, Sabine's functional unit of acoustical absorption was measured in terms of the number of running feet of seat cushions. The seat cushions themselves were, in a crude sense, an acoustical reference material. However, this was quite unsatisfactory and more satisfactory determinations of acoustical absorption in terms of the dimensionless fractional energy absorption were soon developed. The principal reason that reference materials are not used in acoustical measurements is that the acoustical properties of materials are related to atmospheric properties such as humidity and temperature, and to other physical parameters which are often not well controlled. Because of this dependence upon other physical phenomena, most of the measurement procedures have not evolved so as to require reliance upon the acoustical properties of reference materials, an exception being the case of ultrasonic non-destructive testing, as discussed in Section 2.2.2.1.

2.2.5. Science and People

Acoustics has traditionally been a discipline in which the major contributions have been provided by physicists and mathematicians. Early in the twentieth century, however, the technological developments in the field of electroacoustics and electronics rapidly led to the expansion of the discipline to include important contributions from the fields of electrical engineering. The development of physiological acoustics, psychoacoustics, and social sciences such as audiology are important related disciplines. The recent growth of noise control technology has led to the inclusion of such disciplines as mechanical engineering, engineering mechanics and aerospace engineering. Thus the scope of acoustics has become more interdisciplinary than at any previous time. However, this is but one more manifestation of the centrality of the phenomena of sound to our culture.

Every person who performs an acoustical measurement is a participant in the National Measurement System. Yet, there has been relatively little awareness on the part of acousticians of the desirability of explicit understanding of the structure of such a system. Without such an understanding, the participants cannot identify other individual or institutional participants or user groups, and cannot effectively interact with the system to improve their measurement processes or operations.

In retrospect, it seems probable that this neglect of awareness of the structure of the National Measurement System has contributed to the proliferation of inconsistent, inaccurate, and imprecise measurement methodologies in acoustics. An increasing awareness of the necessity for national and international consistency and for the relevant undergirding scientific research on the part of participants in the National Measurement System may result in the improvement of measurement standards. This increased awareness may be brought about by studies of the structure of the system itself. One of the objectives of this report is to contribute to such an increased awareness.

The principal relevant professional society in the United States is the Acoustical Society of America (ASA) which is a member society of the American Institute of Physics (AIP). Other relevant important professional societies include the:

... Audio Engineering Society (AES)
... Institute of Noise Control Engineering (INCE)
... Institute of Electrical and Electronic Engineers (IEEE)
... American Society of Mechanical Engineers (ASME)

There are three types of publications which serve to disseminate knowledge in this discipline, exclusive of corporate or governmental contractor's reports. These categories are Journals, Special Interest Magazines, and News Letters. Several of the more prominent of these publications are presented in the following list:

Journals

Acustica [German]
IEEE Transactions on Audio and Electroacoustics
IEEE Transactions on Ultrasonics
Journal of Applied Acoustics [British]
Journal of the Acoustical Society of America
Journal of the Audio Engineering Society
Journal of Noise Control Engineering
Journal of Sound and Vibration [British]
Soviet Physics - Acoustics [Russian/English Translation]

Special Interest Magazines

Noise News
Sound and Vibration

News Letters

Noise Control Report
Noise Regulation Reporter

In recognition of the interdisciplinary

nature of acoustics, graduate university curricula have been developed to provide the interdisciplinary preparation required for contemporary acousticians. These curricula provide programs of study including course work in Physics, Applied or Engineering Mathematics, Engineering Mechanics and/or Mechanical Engineering, Electrical Engineering, and Computer Science. Interdisciplinary programs directed toward the training of Clinical Audiologists have also evolved. The Acoustical Society of America has a committee to study Education in Acoustics, and the results of their studies document available graduate education in acoustics, and are to be found in the literature [25].

The number of institutions having graduate programs directed toward a degree in acoustics is relatively small, although a significantly larger number of institutions offer undergraduate or isolated graduate courses in acoustics within the framework of curricula in the related disciplines. Graduate level education in acoustics is concentrated principally at:

Catholic University
Massachusetts Institute of Technology
North Carolina State University
Pennsylvania State University
Purdue University
University of Houston
University of Pittsburgh
University of Texas (Austin)

By virtue of contact with ongoing research programs at several of these universities NBS is fortunate to have direct contact or interactions with all of the above institutions except the University of Pittsburgh.

In addition, faculty members of the following institutions serve or have served on the ad hoc Advisory Panel on Acoustics:

Columbia University
George Washington University
Pennsylvania State University
University of Houston
University of Rochester

2.3. Realized Measurement Capabilities

2.3.1. General Patterns

The motivating factor for many acoustical measurements is often tied to some subjective (e.g., noisiness, annoyance, etc.) reaction of people toward a noise source. Many difficulties exist in developing reliable algorithms to predict human response to noise from physical measurements of sound, and the discrepancies among the data collection and processing measurement methodologies and between the various predictions of human response are often large. Because the subjective response to noise cannot be accurately predicted, appreciable measurement inaccuracies and imprecision have often been tolerated in the required physical measurements of noise.

Loudness judgements may be taken as a specific example. (Loudness, in this case, can be defined as a listener's perception of the intensity of a sound or noise.) In psychophysical experiments on loudness, subjects are often requested to judge when one sound is equal in loudness to another. The standard deviations of equal loudness judgements made by a group of 20 to 30 people will typically range from 4 to 12 dB. Furthermore, when different laboratories repeat the same experiment employing slightly different conditions (e.g., free field vs. earphones, method of adjustment vs. constant stimuli, etc.), differences in the mean equal loudness judgements vary from 10 to 20 dB in many cases.

Furthermore, there exists the problem of which method should be used. For example, Corliss and Winzer at the National Bureau of Standards applied several algorithms for computing loudness to the same sounds [26]. The different loudness scales yielded answers that were discrepant by as much as 9 dB, and discrepancies among any of the algorithms and the actual judgement of a jury of subjects reached 13 dB. Thus, not only do the various psychoacoustic scales disagree among themselves, but they may all be at still greater variance with the actual reactions of people.

The accuracy and precision required for important acoustical measurements and for the associated instrumentation are somewhat more stringent; yet, there is a need for appreciable improvements. For example, the

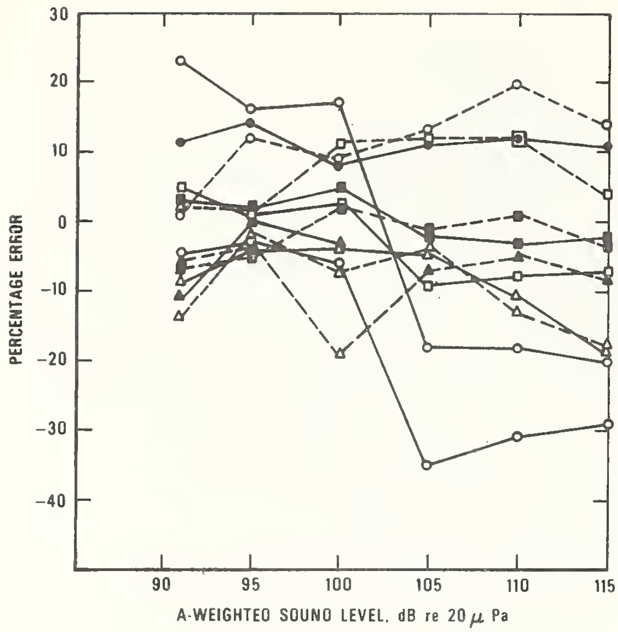


Figure 5. Results for several commercial noise exposure meters tested in a random incidence.

procedure for calibrating audiometers permits ambiguities in tolerance limits. The present American National Standards Institute standards [11,27] allow an audiometer with an error of 11.5 dB at 8000 Hz to be calibrated as being within the allowed 5 dB tolerance. This anomaly is due to the cumulative calibration error effects allowed by the standard. Obviously, tightening of the tolerance for audiometer calibration equipment is desirable.

In general there have been no measurement or instrument standards which spell out accuracy and precision requirements for environmental noise monitoring. For example, in the case of integrating sound level meters, the lack of applicable performance standards and the competition among different manufacturers to produce low-cost, compact instruments has resulted in some equipment that exhibits very poor performance. Recent NBS tests [28] on a number of commercial portable exposure meters intended for occupational noise monitoring yielded the results shown in figure 5. The quantity being measured was the percentage of allowable noise exposure. The errors are relative to 100 percent of allowable exposure. Plus or minus 5 to 10 percent would be considered good performance. Based on this criterion, of the twelve devices tested, only three passed this particular test.

In terms of accuracy, American National Standard S1.4-1971 describes three basic types of sound level meters. Accuracy requirements are given in terms of allowable error tolerances relative to the specified overall response of the instrument. The tolerances, as indicated, vary from ± 1.0 decibel for the mid-frequency range for the Type 1 meter, to +7.5, $-\infty$ decibels at 10 kHz for the least precise type, Type 3.

Manufacturers of sound level meters usually claim compliance with American National Standard S1.4. Purchasers of meters are likely to require such compliance or else use S1.4 as a basis for preparing specifications. It is likely that many manufacturers do not have the proper facilities to determine compliance. It should be noted that "type testing" of meters is a substantial job and even with a semi-automated, dedicated facility, would still probably cost on the order of $500 per meter. Because of the intricacies of compliance testing sound level meters it is doubtful whether most of the sound level meter manufacturers are currently using thorough and extensive techniques.

Unfortunately, much of the value of American National Standard S1.4-1971 is diluted by the absence of a standard on *acoustical calibration procedures* for sound level meters. Performing an adequate calibration requires that the detailed procedures be carried out by highly skilled personnel.

The highest degree of acoustical measurement accuracy is usually to be found in the microphone calibration process. This is a consequence largely of the tight control of the variable factors in the process, concern for attention to details and good measurement practices, and caution in the interpretation of experimental data.

The estimated accuracy of NBS pressure reciprocity calibration is 0.1 decibel. The accuracy will, typically, be worse than this for random incidence conditions since it is difficult to produce a sound field which is spatially uniform. Nonetheless, this degree of accuracy is an important objective when legal limits are involved such as compliance with OSHA regulations or aircraft noise certification. Unfortunately, inaccuracies in level of typically 1.0 dB are not uncommon for acoustical measurements.

Many companies and institutions maintain sound measurement standards laboratories of their own. The size and extent of each is related to the companies' activities. Some of the laboratories perform reciprocity calibrations with special, commercially-available equipment, but such equipment does not yield as accurate a calibration as is available from NBS. A small number of laboratories have calibration equipment modeled after NBS and obtain accuracies approaching ours for certain types of measurements.

The calibration provided by a microphone manufacturer is usually accurate. However, such is not always the case. For example, for one brand of microphone, a calibration chart is included which is based on the use of non-standard calibration techniques. For one-inch diameter microphones, differences from the NBS calibration of as much as 1.5 decibels exist in the neighborhood of the microphone resonance. A short paper [29] has been published describing the differences in calibration and the reasons for them.

Despite the fact that inaccuracies found in acoustical measurements can be appreciable, as the preceding has indicated, the inaccuracy to be found in the technology of ultrasonic non-destructive testing is believed to be even more appreciable. The National Bureau of Standards is currently directing attention to this technology, and is studying the response of reference blocks to acoustic signals. Realizing that these reference blocks are used for the purpose of system calibration, data were obtained upon several sets of commercially available distance-amplitude blocks. The ultrasonic response data are shown in figure 6, and indicate that although the response amplitude generally drops off significantly with increasing metal thickness, for one set of blocks there was an anomalous response, amounting to differences as large as 800%. This is probably due to uncontrolled metallurgical properties of the material. Differences of this order of magnitude not only render this specific set of blocks unusable, but would, if representative of those generally used make the use of ultrasonics as a means of non-destructive testing and evaluation a source of inequity in trade. Manufacturers cannot rely upon the data obtained from such an empirical technology to develop product standards.

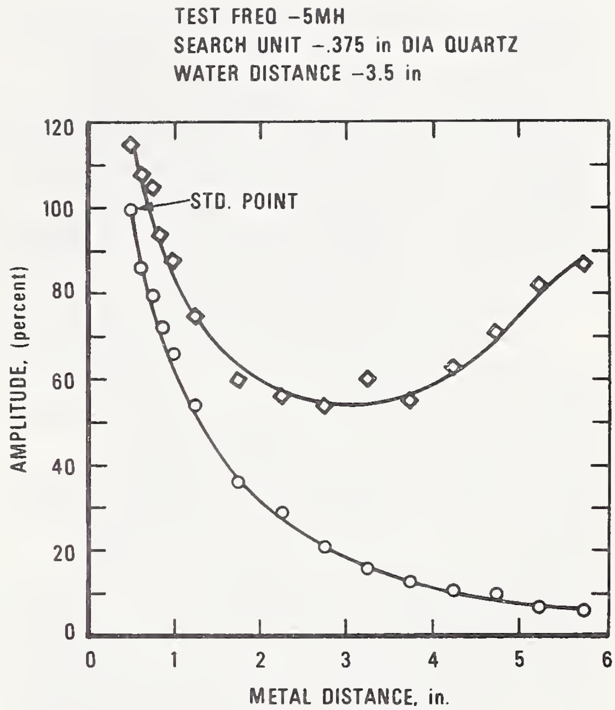


Figure 6. Ultrasonic response amplitude data for distance - amplitude reference blocks.

The current NBS program in ultrasonic non-destructive testing and evaluation is leading to the discovery of the causes and elimination of the variability of the reference blocks as a major source of error in ultrasonic measurement systems.

2.3.2. Dependence Upon Environmental Factors

There are two principal active concerns about the dependence of acoustical measurement instrumentation and measurement methodologies upon environmental factors. These concern the stability of the instrumentation calibration over long periods of time and under varying environmental conditions, and the dependence of the data upon poorly characterized environmental facters.

In obtaining long term measures of such factors as community noise, the temperature dependence of the instrumentation may be an important factor. Recent National Bureau of

Standards services performed to evaluate noise monitoring systems for the Department of Housing and Urban Development have disclosed an unanticipated significant dependence of microphone sensitivity upon temperature which will require design changes. An additional investigation is currently in progress to evaluate the dependence of microphone sensitivity upon temperature and humidity for condenser, electret and ceramic microphones.

Current attention directed to the quantitative characterization of noise emissions from common noise sources such as automobiles, trucks, portable air compressors, etc., has disclosed the necessity for accurate characterization of such factors as the acoustic impedance at several angles of incidence (including grazing) of concrete, macadam, or grass covered surfaces. Recognition, in fact, of the impossibility of reliable characterization of the acoustic properties of grass has led to the use of synthetic turf in a measurement methodology directed toward measurement of the noise emission of small engine powered equipment (e.g., lawn mowers, snowmobiles, etc.) [30].

2.3.3. Adequacy Versus Needs

There are a large number of important acoustical measurement standards related to numerous special purpose measurement procedures.

While these standards may have been adequate in the past, they may not be adequate for future needs. Due to the economic and/or legal implications of present and pending noise control legislation, the degree of accuracy and precision which can be anticipated with employment of a specific measurement methodology is now receiving increased attention. For standards and regulations to be effective and reasonable uncertainties in the measurement methods should be as small as practicable. Compliance cannot be determined unless the measured levels are lower than the specified limit by an amount at least equal to a realistic estimate of the measurement uncertainty. Uniformity of enforcement -- i.e., consistency among measurements by different officials -- is only possible if the tolerance between the legal limit and the enforcement limit is set at the measurement uncertainty representative of typical field measurement conditions.

The largest uncertainty likely for measurements by the least competent official, using the most inaccurate or imprecise equipment allowable, under the least favorable test conditions, must be considered in the process of setting the relation between the legal limit and the enforcement limit. If this measurement uncertainty is large, the enforcement agency's problems are increased. If the enforcement level is set above the legal limit, it appears that the agency is not enforcing the desired noise abatement level. If the enforcement level is set below the legal limit, manufacturer's incur increased compliance costs. Thus, the situation must be optimized, so that although a certain degree of measurement certainty is sacrificed, the cost of compliance is kept at a reasonable level.

The question might well be raised as to whether close measurement tolerances -- attainable by careful control of environment, operating procedures, and measurement procedure -- are justified in view of the uncertainties in the application of the resultant noise rating to predict in-service noise levels and its resultant effects. First, the total error in prediction is the *sum* of the errors *in rating, in predicting in service levels and in predicting the resultant effects*. Reducing the rating error thus reduces the total error; however, it would be economically wasteful to insist upon high levels of accuracy and precision for rating measurements if the errors in predicting in-service levels and resultant effects are relatively gross and difficult to control. Second, application errors and, to some extent, effect-prediction errors tend to average out from one application to another; systematic errors are repetitive. Third, when noise ratings are used to compare the performance of competitive products, difficulties in enforcement, inequities in trade and excessive costs may be incurred.

Because the increase in concern over noise and attention given to the accuracy and precision of determining noise emission are very recent developments, essentially no one -- including NBS -- has, as yet, adequately evaluated the uncertainties associated with various techniques for measuring noise emission. NBS is currently responding to this need to evaluate measurement uncertainty by conducting a project in the area of transportation noise. Because of increasing concern with the impact of transportation noise on communities, there has been an increase in the number of motor vehicle noise regulations at all levels of government. As regulations become more widespread, the accuracy and precision of vehicle noise measurements become more critical since each uncertainty in the measurement requires a corresponding increase in the margin that manufacturers must allow between the regulated noise limit and vehicle design levels. Although considerable uniformity has been achieved by existing voluntary standards, there remain significant variations between noise measurements made at different sites or at different times on the same site. These variations are attributable to differences in the environment, including site and meterological influences. Thus, there is a need for systematic investigation of the various environmental and test site effects on noise generation, radiation and/or propagation. Although it may not be feasible to determine "correction factors" for environmental effects, it is fully expected that the data obtained from this experiment will reveal the magnitude of variations in the measurement and provide a broad enough information base for study of the underlying physical mechanisms [31].

2.4. Dissemination and Enforcement Network

2.4.1. Central Standards Authorities

Because the standards system in this nation is voluntary, there is no central standards authority, as such, and NBS has no specific legal "authority" in the dissemination of acoustical measurement standards, in contrast to the situation in some other nations. NBS staff members serve active roles in the professional society and voluntary concensus standards groups, but as an institution NBS does not serve to disseminate or enforce standards for acoustical measurements. The scope of institutional involvement is principally limited to the individual participation of NBS staff members within the existing voluntary concensus standards-writing groups, to the critical review of existing standards and scientific contributions toward the evolution of improved measurement standards, and to the provision of advisory information covering measurement methodologies to other Federal agencies, State and local governments, and to the general public.

2.4.2. State and Local Offices of Weights and Measures

At the present time no state or local offices of weights and measures are known to be concerned with the subject of acoustics or acoustical measurements. This situation is apt to change as our society becomes more concerned with the measurement of noise emissions, but these considerations are relatively recent elements in our society, and this institutional element of the standards and enforcement network has not yet become active in this field.

2.4.3. Standards and Testing Laboratories and Services

2.4.3.1. Types of Acoustical Standards and Testing Laboratories

Private (non-governmental) acoustical standards and testing laboratories exist as both corporate industrial and independent laboratories. The industrial laboratories largely exist to serve the needs for acoustical measurements of corporate research and/or design engineering groups. The motivation for these measurements is frequently related to noise control engineering, product improvement, or product quality control considerations. The independent laboratories provide testing and measurement services to industry wide groups, to noise control consultants, industrial clients who do not maintain their own testing laboratories, and to municipal, state and Federal governmental units.

Governmental laboratories provide limited acoustical testing and measurement services to support review of measurement procedures or procurement specifications or for the furtherance of basic research on acoustical phenomena.

Table 4 presents a tabulation of known accustical laboratories, together with information pertaining to the relevant acoustical measurement capabilities.

2.4.3.2. Functions Performed

The industrial research and independent testing laboratories are principally concerned with determining the following types of information:

... mechanisms of aerodynamic noise emissions

Table 4. Existing acoustical laboratories.

	Type of Test Facilities[1]	Acoustical Measurement Capabilities[2]
Industrial Laboratories:		
Armstrong Cork Company	a,b,d	1,2,4,5,10,13
Barry Controls	a,c,	4,5
Carrier Corporation	a	4,5
Celotex Corporation	a	4,5
Conwed Corp. (formerly Wood Conversion Co.)	a	4,5
Domtar LTD., Quebec	a,b,d	1,2,4,5
International Business Machines (IBM)	a,c	4,5,10
Jim Walter Corp.	a,b	1,4,5
Johns-Manville Research and Engineering Center	a	4,5
Lockheed Missile and Space	a,b,c	1,4,5
Lord Manufacturing Company	a,b	1,4,5
McDonald Douglas Corporation	a,b,c	1,4,5
Minnesota Mining and Manufacturing Co. (3M)	a	4,5
National Gypsum Company	a,b,d	1,2,4,5
Noise Unlimited, Inc.	a,c	4,5
Ohio Research Corp., Donn Products, Inc.	a,b	1,4,5
Odgen Technology Laboratories, Inc.	a	4,5
Owens-Corning Fiberglas Corp.	a,b,d,g,	1,2,4,5,10,13
Pittsburgh Corning	a	4,5
United Acoustic Consultants	c,e	5,10
United States Gypsum Company	a,e	1,2,4,5
Vibro-Acoustics Ltd. A Douglas Engineering Co.	a,b	1,4,5
York, Borg-Warner	a	4,5
Independent Laboratories:		
Cedar Knolls Acoustical Laboratories	a,b,d,g,i,j,	1,2,3,4,5,7,9,10,13
Geiger & Hamme, Inc.	a,b,d	1,2,3,4,5,10,13
Intest (International Acoustical Testing Labs)	a,b,c,d,g	1,2,3,4,5,8,10
Kodaras Acoustical Laboratories	a,b,d,g,j	1,2,3,4,5,7,8,9,10,13
Ling Temco Vought, Inc., Research Center	a,g,i	4,5,11
Riverbank Acoustical Laboratories of I I T R I	a,b,d,g	1,2,3,4,5,9,10
Wyle Laboratories	a,b,c,d,g,i	1,2,3,4,5
Government Laboratories:		
NASA Langley Research	a,c,g	4,5,10
NBS Laboratories at Gaithersburg	a,c	4,5,6,10,12,13,14,15
National Research Council of Canada	a,b,d,g	1,2,3,4,5,8,10,13,14,15
Wright Patterson Air Force Base	a,b,c,g,h,i	1,4,5,6,10,11
Academic Laboratories:		
Illinois Inst. of Technology, Research Inst.	a,c,g,i	4,5,11
Pennsylvania State University	a,c,g,h,j	4,5,6,7,8,11,12,13,14,15
Purdue University	a,c,g,j	4,5,7,9
University of California	a,b	1,4,5
University of California, Los Angeles	a,b,c,i	1,4,5,11
University of Houston	c	5
University of Texas	a,c	4,5

[1]Type of test facilities in existing acoustical laboratories in the U. S.:

Evaluation of existing acoustical laboratories in this country is based on the nature of their specialized facilities. Those facilities that are needed for the building acoustics portions of the sound, audition and noise abatement program may be categorized as follows:

a. Reverberation chamber
b. Transmission chamber
c. Anechoic chamber
d. Impact testing chamber
e. Field test simulation spaces in an actual building
f. Plumbing sound facilities
g. Machinery sound facilities
h. Audition chamber with observation room
i. Acoustical scale model test facilities
j. Air handling systems and terminations sound test facilities

[2]Acoustical Measurement and Service capabilities of the existing acoustical laboratories in the U. S.:

1. Airborne sound inslation of building partitions
2. Impact sound insulation of floor-ceiling assemblies
3. Airborne sound insulation of exterior walls & roofs
4. Sound absorption of acoustical & architectural materials
5. Sound power output of small noise sources, machinery & household appliances
6. Psychoacoustics & loudness
7. Heating, ventilating & air-conditioning system noise
8. Structure-borne noise & vibration of building structures
9. Sound attenuation of silencers & mufflers
10. Flow resistance & acoustical impedance of sound absorbing materials
11. Acoustical scale modeling
12. Calibration of microphones, sound level meters, noise dosimeters
13. Technical consultation re acoustical problems, noise abatement & control
14. Advisory services coordinating government & private standards re acoustics, noise criteria & abatement
15. International & domestic standardization activities.

... noise emissions of business machinery

... noise emissions of heating, ventilating and air conditioning systems

... noise abatement properties of mufflers and duct silencers

... acoustic transmission properties of building systems

... acoustical properties of ceiling and wall covering materials and constructions

... acoustic absorption of fibrous materials

... dynamic mechanical and acoustical properties of floor coverings and constructions

... structural vibration control and structure-borne sound abatement systems.

Governmental acoustical laboratories are not only fewer in number, but are also relatively more limited in scope than the industrial or independent testing laboratories.

The Institute of Environmental Sciences has recently initiated a survey of approximately 200 laboratories to determine more detailed information on the facilities and services offered by these laboratories. The preliminary results of the survey are to be published in the March/April 1975 Institute of Environmental Testing Journal, with more detailed information to be released in late 1975 as an IES Report. Although this survey concerns itself in part with consideration of the environmental testing aspects of acoustical measurements, i.e., noise induced structural fatigue, the results of this study should be of considerable general interest.

2.4.3.3. Detailed Description of a Representative Industrial Laboratory

A well-equipped representative industrial laboratory which was visited to obtain information for the purposes of this report had the following major facilities:

... 200 m^3 anechoic chamber with removable floor wedges to convert the facility for use as a "semi-anechoic" facility.

... 200 m^3 reverberation room with removable panel, coupling into an adjacent

... 100 m^3 reverberation room

... real time analyzer, coupled into a digital computer for digital signal processing

... instrumentation to enable the measurement of sound power emissions in free-field, free-field over reflecting plane, and reverberation room environments, under digital computer control

... instrumentation for the measurement of acoustic absorption coefficients.

The technical staff of this laboratory consists of three full-time engineers, two technicians, and secretarial help. The principal service offered by this laboratory is product research and development and implementation of product noise control measures. The facilities had been specifically constructed on a remote site at a corporate research facility primarily to enable the measurement of product noise emissions and for research purposes.

Another facility visited by NBS personnel was an independent testing laboratory with facilities specifically devised to enable the measurement of the noise emissions of air conditioning equipment. Because these measurements require that the equipment be operated under load, this laboratory has extensive facilities to control the temperature and humidity over wide ranges on both sides of the air-conditioning equipment. In addition, the reverberation room facilities were equipped for the measurement of the impact noise properties of floor-ceiling assemblies. The clients of independent laboratories such as this include the manufacturers of commercial grade carpeting and resilient floor coverings, manufacturers of heating, ventilating, and air conditioning equipment, and trade organizations.

2.4.3.4. Interrelationships

The most common inter-relationship of these laboratories is to be found in the common professional affiliations of the staff members. The senior staff members generally serve on the committees of the voluntary concensus standards groups such as the American Society for Testing and Materials, American Society of Heating, Refrigerating and Air Conditioning Engineers, etc. In so doing they strive to represent the desires of their employers as well, of course, as to serve their own concern for scientific factual objectivity. However, in their desire to represent the interests of their employers or firms, there is the possibility that they will tend to promote the acceptance or continued acceptance of an outmoded facility or test method.

Generally speaking, the specifications of voluntary test standards are written so that most of the existing laboratories can meet them. However, detailed instructions and specifications for the construction of new laboratories are given in most standards, with the objective of improving future measurement accuracy within and among laboratories. Some facilities are too small, not equipped for accurate measurements, and are obsolete by present-day standards. In a few instances, laboratories have developed and use their own methods of test in preference to the recognized standards because they feel the latter are unrealistic or misleading -- particularly with respect to airborne and impact sound insulation measurements.

As can be seen in table 4, there is a limited number of architectural acoustic test facilities. It should be noted that only twelve of the laboratories listed have facilities for conducting both airborne and impact sound insulation measurements of wall and floor constructions. Ten laboratories have facilities for measurements of only airborne sound insulation of wall constructions. These statistics reflect not only the expensive nature of these test facilities, but also the fact that the measurement processes are under the direction of a relatively small number of engineers.

2.4.4. Regulatory Agencies

The principal involvement of regulatory agencies with acoustics, and more specifically, with acoustical measurements is concerned with the regulation of environmental noise. Much of the material presented in Section 2.4.4. is drawn from an appendix entitled "Environmental Noise Regulatory Structure", by Dr. Louis Mayo and Mr. Robert C. Ware, in the report of the Conference on Acoustics and Societal Problems [32]. Extensive quotations are used because of the apt and succinct manner in which the authors have described the structure. Additional material is used to describe the detailed structure of municipal noise regulatory efforts, and is drawn from the work of Bragdon [33].

2.4.4.1. Local Regulatory Efforts

"Most noise regulation has traditionally been at the local level. It has suffered from the low priority given to noise control by the police forces and the community as a whole. Cities have not had the technical knowledge or the financial resources with which to combat noise effectively.

"Much local noise regulation is in the form of general laws prohibiting loud and unnecessary noise. The most popular type is that patterned after the Model Ordinance Prohibiting Unnecessary Noise of the National Institute of Municipal Law Officers (NIMLO) (1948). The NIMLO ordinance prohibits all loud and unreasonable noise and specifies certain prohibited noises such as those of loud animals and badly loaded cars and trucks.

"More cities are developing programs to cope with excessive noise. Some have established noise abatement offices with special teams whose duty is to monitor noise around the city. City noise laws are becoming more sophisticated, substituting noise level limits for the former subjective standards. These laws also provide for tougher standards over time. The success of city anti-noise programs will depend upon enforcement of these new laws. Unfortunately, there is a lack of trained personnel to handle noise law enforcement. Enforcement also provides strains on the already over-burdened budgets of many of the nation's cities." [32]

The compilation shown in table 5 lists 440 municipalities. These ordinances now represent a combined population in excess of 62 million people. "There is a continuing interest to enact legislation with quantitative noise emission requirements. In many cities ordinances previously containing non- quantitative or general nuisance provisions have been replaced with quantitative noise emission requirements.

"The ordinances are organized by category including: Nuisance, Zoning (Land Use), Vehicle, Aircraft, and Building Regulations containing acoustical criteria

Table 5. Municipal noise ordinances: 1976

	Nuisance	Zoning	Vehicle	Recreational Vehicle	Railroad	Aircraft	Construction	Building
■ Regulation includes acoustical criteria	157	219	138	50	16	26	44	26
□ Regulation does not include acoustical criteria	410	22	115	20	9	9	71	9
— No regulation	85	411	399	582	627	617	537	617

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
ALABAMA									
Anniston	31,533	□	—	□	—	—	—	□	—
Birmingham	300,910	□	—	—	—	—	—	—	—
Irondale	3,166	■	□	—	—	—	—	—	—
Madison	3,086	—	■	—	—	—	■	—	■
Mobile	190,026	□	—	—	—	—	—	—	—
Montgomery	133,386	□	—	—	—	—	—	—	—
ALASKA									
Anchorage	48,081	□	—	■	■	—	—	—	—
Juneau	6,050	□	—	—	—	—	—	—	—
Ketchikan	6,994	□	—	—	—	—	—	—	—
ARIZONA									
Flagstaff	26,177	□	—	□	—	—	—	—	—
Phoenix	581,562	□	—	□	□	—	—	—	—
Scottsdale	67,823	■	■	■	—	—	—	—	—
Tempe	62,907	■	■	■	—	—	■	—	—
Tucson	262,933	■	■	—	—	—	—	—	—
ARKANSAS									
Little Rock	132,125	□	—	—	—	—	—	—	—
Pine Bluff	57,389	□	—	—	—	—	—	—	—
CALIFORNIA									
Alhambra	62,125	■	—	—	—	—	—	—	—
Amador	156	■	—	—	—	—	—	□	—
Anaheim	166,704	■	■	■	—	—	—	■	■
Arcadia	43,867	■	—	—	—	—	—	—	—
Belmont	23,667	■	—	—	—	—	—	—	—
Berkeley	116,716	■	—	—	—	—	—	—	■
Beverly Hills	33,416	■	—	■	—	—	—	■	■
Buena Park	63,646	■	■	—	—	—	—	—	—
Burbank	88,871	■	■	□	□	—	—	□	—
Burlingame	27,320	□	—	—	—	—	—	—	—
Capitola	7,175	□	—	—	—	—	—	—	—
Ceres	8,675	□	—	□	—	—	—	□	—
Chico	19,580	■	—	—	—	—	—	■	—
Commerce	10,662	—	■	—	—	—	—	—	—
Costa Mesa	72,660	■	■	■	—	—	■	■	—
Cotati	2,081	■	■	—	—	—	—	—	—
Cudahy	17,040	—	□	—	—	—	—	—	—
Culver City	37,600	■	—	—	—	—	—	—	—
Cupertino	18,216	□	—	—	—	—	—	—	—
Oel Mar	4,475	□	—	□	—	—	—	□	—
Oel Rey Oaks	1,830	□	—	□	—	—	—	□	—
Oowney	88,442	■	—	■	■	—	—	□	—
Duarte	15,100	■	—	□	—	■	—	□	—
El Cajon	52,273	—	■	—	—	—	—	—	—
El Segundo	15,620	■	■	□	—	—	—	□	—
Escalon	1,834	■	—	■	■	—	—	—	—
Foster City	18,650	■	—	—	—	—	—	—	—
Fountain Valley	31,826	■	■	—	—	—	—	■	—
Fresno	165,972	■	■	—	—	—	—	■	—
Fremont	100,869	—	■	□	—	—	—	—	—
Gardena	41,021	■	■	■	■	—	—	■	■
Garden Grove	121,371	—	—	—	—	—	—	—	□
Glendale	132,752	■	■	□	—	—	—	□	—
Glendora	31,349	■	■	□	—	—	—	□	—
Gustine	3,546	■	■	■	—	—	—	—	—
Hayward	93,058	□	—	—	—	—	■	—	■
Hemet	12,252	□	■	—	—	—	—	—	—
Hermosa Beach	17,412	□	■	□	—	■	—	—	■
Huntington Beach	17,412	□	—	□	—	—	□	□	—
Huntington Park	33,744	□	—	—	—	—	—	—	—
Inglewood	89,985	■	■	—	—	■	■	—	—
Laguna Beach	15,100	—	■	—	—	—	—	—	—
Lakewood	82,973	□	■	—	—	■	■	■	—
La Mesa	44,509	—	■	—	—	—	—	—	—
La Puente	31,450	■	—	—	—	—	—	□	—
Larkspur	10,487	■	—	■	■	—	—	—	—
Lodi	28,691	—	■	—	—	■	—	—	—
Lomita	19,784	■	■	—	—	—	—	—	—
Long Beach	358,633	■	—	■	—	—	■	■	—
Los Altos Hills	6,853	—	■	□	—	—	—	—	■
Los Angeles	2,816,061	□	■	■	—	—	—	□	■
Los Banos	9,188	■	—	■	■	—	—	—	—
Lynwood	43,353	—	■	□	—	—	—	—	—
Manteca	13,845	—	■	—	—	—	—	—	—
Menlo Park	26,826	□	—	—	—	—	—	—	—
Milpitas	32,400	—	□	—	—	—	—	—	—
Modesto	75,800	■	—	—	—	—	—	□	—
Monrovia	30,015	—	—	—	—	—	—	—	■
Monterey	26,302	■	■	—	—	—	—	—	—
Newark	27,153	■	■	—	—	—	—	—	■
Newport Beach	49,422	■	—	■	■	—	—	—	—
Norwalk	91,827	—	□	—	—	—	—	—	—
Novato	31,006	■	—	■	■	—	■	■	—
Oakland	361,561	□	■	—	—	—	—	—	—
Orange	77,365	■	■	—	—	—	—	■	—
Pacifica	36,020	□	—	—	—	—	—	—	—
Palmdale	10,600	—	—	—	□	—	—	—	—
Palo Alto	55,966	■	■	—	—	—	—	—	—
Pasadena	112,951	■	■	□	—	—	—	■	—
Perris	5,100	■	—	—	—	—	—	—	—
Petaluma	31,150	—	■	—	—	—	—	—	—
Placentia	30,200	■	—	—	—	—	—	—	—
Pleasant Hill	27,150	■	—	■	—	—	—	□	—
Red Bluff	7,676	□	—	—	—	—	—	—	—
Redding	16,659	■	—	■	■	—	—	—	—
Redondo Beach	64,000	■	—	—	—	■	—	—	—
Richmond	79,043	—	■	■	—	■	■	—	—
Rocklin	3,039	—	■	—	—	—	—	—	—
Roseville	19,950	■	—	—	■	—	—	■	—
Ross	2,742	■	—	■	■	—	—	—	—
Sacramento	254,413	□	—	—	—	—	—	—	—
Salinas	58,893	□	—	□	□	—	—	—	—
San Anselmo	13,031	■	■	■	—	—	—	—	—
San Bernardino	104,251	□	—	—	—	—	—	—	—
San Bruno	38,750	■	—	—	—	—	—	■	—
San Carlos	26,053	—	■	—	—	—	—	—	—
San Clemente	17,063	□	—	—	—	—	—	—	—
San Oiego	696,769	■	■	■	■	—	—	■	■
San Dimas	17,125	□	—	—	—	—	—	—	—
San Francisco	715,674	■	■	■	■	—	—	■	—
San Jose	445,779	—	—	—	—	—	□	—	—
San Juan Capistrano	11,000	■	—	—	—	—	—	—	—
San Leandro	68,698	□	—	—	—	—	—	—	—
San Marcos	3,896	■	—	■	■	—	—	—	—
San Mateo	78,991	□	■	—	—	—	—	—	■
San Rafael	38,977	□	—	—	—	—	—	—	—
Santa Barbara	70,215	□	■	—	—	—	■	—	—
Santa Clara	87,717	□	—	—	—	—	■	—	■
Santa Fe Springs	14,750	—	■	—	—	—	—	—	—
Santa Maria	32,749	—	■	—	—	—	—	—	—
Santa Monica	88,289	—	—	—	—	—	—	—	—
Santa Rosa	50,006	■	■	■	—	—	—	—	—
Saratoga	29,932	■	—	—	—	—	—	—	—
Sausalito	6,158	■	—	□	—	—	—	—	—
Simi Valley	59,832	■	—	—	—	—	—	—	—
South El Monte	13,442	■	—	—	—	—	—	—	—
South Gate	56,909	■	—	—	—	—	—	—	—
South Pasadena	22,629	■	—	□	—	—	—	—	—
Sunnyvale	95,408	□	■	—	—	—	—	—	—
Tracy	14,724	—	■	—	—	—	—	—	■
Torrance	134,584	■	■	■	—	—	—	□	—
Vallejo	74,800	■	—	—	—	—	—	—	—
Victorville	10,845	□	—	—	—	—	—	—	—
Walnut Creek	48,850	□	—	—	—	—	—	□	—
West Covina	74,000	■	—	■	—	—	—	—	—
Whittier	73,400	□	—	—	—	—	—	—	—
COLORAOO									
Arvada	49,083	□	■	■	—	—	—	—	—
Aspen	2,404	□	■	■	—	—	—	—	—
Aurora	74,974	—	■	—	—	—	—	—	—
Boulder	66,870	□	—	■	■	—	—	—	—
Colorado Springs	135,060	□	■	■	—	■	■	—	—
Oenver	514,678	□	■	■	—	—	—	—	—
Dillon	182	—	—	□	—	—	—	—	—
Englewood	33,695	□	■	■	—	—	—	—	—
Fort Collins	43,337	□	■	■	■	—	—	■	—
Lakewood	92,787	■	■	■	■	—	—	■	—
Littleton	26,466	□	■	■	■	—	—	■	—
Wheat Ridge	29,795	□	—	—	—	—	—	—	—
CONNECTICUT									
Berlin	14,149	□	■	—	—	—	—	—	—
Bridgeport	156,542	■	■	■	—	—	—	■	■
Farmington	14,390	■	■	■	—	—	—	—	—
Hartford	158,017	□	—	—	—	—	—	—	□
New Haven	137,707	□	■	—	—	—	—	—	—
Stonington	15,590	□	■	—	—	—	—	—	—
Westport	27,414	—	■	—	—	—	—	—	—
DELAWARE									
Wilmington	80,386	□	■	■	—	—	—	—	—
OISTRICT OF COLUMBIA									
District of Columbia	756,510	□	■	■	—	—	—	—	—
FLORIOA									
Anna Maria	1,400	□	—	—	—	—	—	—	—
Atlantis	844	■	■	—	—	—	—	—	—
Bal Harbor Village	2,104	□	—	—	—	—	—	—	—
Bay Harbor	4,723	□	—	—	—	—	—	—	—
Bay Lake	18	■	—	—	—	—	—	—	—
Boca Raton	28,506	■	—	—	—	—	—	□	—
Cape Canaveral	5,131	■	■	—	—	—	—	—	—

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
Clearwater	52,074	□	–	–	–	–	–	□	–
Cocoa Beach	11,555	–	■	–	–	–	–	–	–
Coral Gables	42,494	■	■	–	–	–	–	□	■
Dania	9,819	□	–	–	–	–	–	–	–
Daytona Beach	47,682	■	–	–	–	–	–	–	–
Deerfield Beach	19,577	■	■	–	–	–	–	–	–
Deland	11,641	–	–	■	–	–	–	–	–
Delray Beach	19,915	□	–	□	□	–	–	□	–
Edgewater	3,348	■	■	■	–	–	–	–	–
Fort Lauderdale	139,590	■	–	■	–	–	–	■	–
Fort Myers	32,563	□	–	–	–	–	–	–	–
Fort Pierce	31,752	□	–	–	–	–	–	–	–
Gainesville	64,510	■	■	■	–	–	–	–	–
Hallandale	32,292	■	–	–	–	–	–	–	–
Hialeah	102,452	□	□	–	–	–	–	–	–
Hialeah Gardens	1,076	■	–	–	–	–	–	–	–
Hollywood	106,873	□	–	□	–	–	–	□	–
Homestead	19,022	□	–	–	–	–	–	–	–
Indian Shores	891	□	–	–	–	–	–	–	–
Jacksonville	528,865	■	■	□	–	–	–	–	–
Lake Buena Vista	22	■	–	–	–	–	–	–	–
Lakeland	45,091	□	–	–	–	–	–	–	–
Lake Park	7,927	■	■	■	■	–	–	■	–
Lake Worth	25,934	□	–	–	–	–	–	–	–
Lauderdale by the Sea	2,941	□	–	–	–	–	–	–	–
Lighthouse Point	11,760	□	–	–	–	–	–	–	–
Madiera	4,769	■	■	–	–	–	–	–	–
Margate	17,153	□	–	–	–	–	–	–	–
Melbourne	40,236	–	■	■	–	–	–	–	–
Miami	334,859	–	■	–	–	–	–	–	–
Miami Beach	89,741	■	■	–	–	–	–	–	–
Miami Shores	9,541	□	–	–	–	–	–	–	–
Miami Springs	13,384	□	–	–	–	–	–	–	–
Miramar	27,132	□	–	–	–	–	–	–	–
North Lauderdale	5,648	□	–	–	–	–	–	–	–
North Miami	42,970	■	–	–	–	–	–	–	–
North Palm Beach	12,056	■	–	–	–	–	–	–	–
Dakland Park	19,700	□	–	–	–	–	–	–	–
Didsmar	2,090	□	■	–	–	–	–	–	–
Dpa Locka	12,924	□	–	–	–	–	–	–	–
Drlando	97,565	□	■	–	–	–	■	–	–
Plantation	29,512	□	–	–	–	–	–	–	–
Plant City	15,781	□	–	–	–	–	–	–	–
Pinellas Park	28,526	□	–	–	–	–	–	–	–
Palm Beach Gardens	8,315	■	■	–	–	–	–	–	–
Pompano Beach	38,544	■	■	■	■	–	■	–	–
Lauderdale Beach	2,941	□	–	–	–	–	–	–	–
Riviera Beach	21,401	□	■	□	–	–	–	–	–
Redington Shores	2,111	□	–	–	–	–	–	–	–
St. Petersburg	216,232	■	■	■	–	–	–	–	–
Sarasota	44,638	□	–	–	–	–	–	–	–
South Oaytona	7,825	–	■	–	–	–	–	–	–
Surfside	3,649	□	–	–	–	–	–	–	–
Tallahassee	72,586	–	–	■	–	–	–	–	–
Tampa	298,740	□	–	–	–	–	–	–	–
Tavares	3,673	□	–	–	–	–	–	–	–
Treasure Island	6,878	□	–	–	–	–	–	–	–
Vero Beach	14,211	■	■	■	■	–	–	–	–
Virginia Gardens	2,592	□	–	–	–	–	–	–	–
West Miami	5,989	□	–	–	–	–	–	–	–
West Palm Beach	27,132	■	–	■	■	–	–	■	–
Winter Haven	16,136	■	■	■	–	–	–	–	–
GEORGIA									
Alma	3,756	□	–	□	–	–	–	–	–
Atlanta	497,421	□	–	–	–	–	–	–	–
Camilla	4,987	□	■	–	–	–	–	–	–
Carrolton	13,520	□	–	□	–	–	–	–	–
Claxton	2,669	–	■	–	–	–	–	–	–
College Park	18,203	■	■	□	–	–	■	■	–
Columbus	154,168	□	–	□	–	–	–	–	–
Cordele	10,733	–	□	–	–	–	–	–	–
Dacala	782	–	–	□	–	–	–	–	–
Danielsville	370	□	–	–	–	–	–	–	–
Decatur	21,943	□	–	–	–	–	–	–	–
Oover	220	□	–	–	–	–	–	–	–
Flowery Branch	761	□	–	–	–	–	–	–	–
Forest Park	19,994	□	–	□	□	□	–	□	–
Griffin	22,734	□	–	–	–	–	–	–	–
Hapeville	9,567	□	–	–	–	–	–	–	–
Kingsland	1,831	□	–	□	–	–	–	–	–
Lake City	2,306	□	–	□	□	–	–	□	–
Louisville	2,691	□	–	–	–	–	–	–	–
Macon	122,423	□	–	□	–	–	–	–	–
Moultrie	14,400	■	■	–	–	–	–	–	–
Newnan	11,205	□	■	□	–	–	–	–	–
Peachtree City	793	–	–	□	–	–	–	–	–
Rincon	1,854	□	–	–	–	–	–	–	–
Riverdale	2,521	□	–	–	–	–	–	–	–
Savannah	118,349	■	■	■	■	–	–	■	–
Tyrone	136	□	–	–	–	–	–	–	–
Warner Robins	33,491	–	■	–	–	–	–	–	–
Waynesboro	5,530	□	–	–	–	–	–	–	–
HAWAII									
Honolulu	324,871	□	■	■	–	–	–	–	–
IDAHO									
Boise	74,990	□	□	□	–	–	–	–	–
Idaho Falls	35,776	–	–	■	–	–	–	–	–
Pocatello	40,036	□	–	■	–	–	–	–	–
ILLINOIS									
Arlington Heights	64,884	–	■	–	–	–	–	–	–
Carbondale	22,816	–	■	–	–	–	–	–	–
Chicago	3,369,359	■	■	■	■	–	–	■	–
Decatur	90,397	□	–	–	□	–	–	–	–
Des Plaines	57,239	□	■	■	■	–	■	■	–
Downers Grove	32,751	■	–	■	–	–	–	–	–
Joliet	80,378	□	–	□	–	–	–	–	–
Marengo	4,235	■	–	■	–	–	–	–	–
Moline	46,237	–	–	■	–	–	–	–	–
Northbrook	27,297	–	–	–	–	–	–	–	■
Park Ridge	42,466	■	–	■	–	–	■	–	–
Peoria	126,963	■	–	■	–	–	–	–	–
Rockford	147,370	□	–	■	■	–	–	□	–
Savanna	4,942	□	–	□	–	–	–	–	–
South Holland	12,619	□	–	–	–	■	–	–	–
Urbana	32,800	□	■	■	■	–	–	■	–
INDIANA									
Evansville	138,764	□	■	■	■	–	■	□	–
Gary	175,415	□	■	□	–	–	–	–	–
Hammond	107,888	□	■	■	■	–	■	–	–
Indianapolis	745,739	■	–	–	–	–	–	–	□
Logansport	19,255	■	–	■	–	–	–	–	–
Lowell	5,822	□	–	–	–	–	–	–	–
Dgden Dunes	982	–	■	–	–	–	–	–	–
South Bend	125,580	□	–	□	–	–	–	□	–
IOWA									
Bedford	2,361	□	–	□	–	–	–	–	–
Cedar Falls	29,597	□	■	■	–	–	–	□	–
Council Bluffs	60,348	□	–	□	□	–	–	□	–
Davenport	98,469	□	–	□	–	–	–	□	–
Des Moines	200,587	□	–	□	–	–	–	□	–
Dubuque	62,309	□	■	■	–	–	–	–	–
Pella	6,668	–	–	■	–	–	–	–	–
Sioux City	82,925	□	□	□	–	–	–	–	–
Storm Lake	8,591	□	■	■	–	–	–	–	–
Waterloo	75,533	□	–	–	–	–	–	–	–
KANSAS									
Lawrence	45,698	□	–	□	–	–	–	–	–
Prairie Village	28,138	□	■	■	■	–	–	■	–
Wichita	276,534	□	–	□	–	–	–	–	□
KENTUCKY									
Covington	52,535	■	–	□	□	–	–	□	–
Lexington	108,137	□	–	–	–	–	–	–	–
Louisville	361,472	–	–	■	■	–	■	■	–
Newport	25,998		–	–	–	–	–	–	–
LOUISIANA									
Baton Rouge	165,963		–			–	–		–
New Orleans	593,471			–	–	–	–	–	–
MARYLAND									
Baltimore	905,759	□	■	–	□	–	–	–	–
Cumberland	29,724	□	–	–	–	–	–	–	–
Rockville	41,564	□	–	–	–	–	–	–	–
MASSACHUSETTS									
Acton	14,770	–	□	–	–	–	–	–	–
Boston	641,070	■	■	■	–	–	–	–	–
Concord	16,148	□	–	□	□	–	–	□	–
Fall River	96,898	□	□	–	–	–	–	–	–
Milford	19,352	–	■	–	–	–	–	–	–
Newton	91,263	□	–	□	–	–	–	–	–
Pittsfield	57,020	■	–	■	–	–	–	–	–
Springfield	163,905	□	■	–	–	–	–	–	–
Worcester	176,572	□	–	–	–	–	–	–	–
MICHIGAN									
Ann Arbor	99,797	□	■	■	–	–	–	–	□
Augusta Township	1,016	□	–	–	–	–	–	–	–
Beverly Hills	13,598	□	–	–	–	–	–	–	–
Birmingham	26,170	□	–	■	–	–	–	–	–
Comstock	5,003	■	–	■	■	–	–	–	–
Dearborn	104,199	□	–	–	–	–	□	–	–
Detroit	1,512,893	□	–	–	–	–	–	–	–
Farmington	10,329	□	–	–	–	–	–	–	–
Gladwin	3,624	■	–	■	–	–	–	–	–
Grand Rapids	197,649	■	■	■	■	–	–	■	■
Harbor Springs	5,261	■	■	■	–	–	–	–	–
Kalamazoo	85,555	□	■	■	■	■	–	■	–
Meridian Township	23,817	■	■	■	■	–	–	–	–
Milford	4,699	–	■	–	–	–	–	–	■
Pontiac	85,279	□	■	–	–	–	–	–	–
Ravenna	851	□	–	–	–	–	–	–	–
Saginaw	91,849	□	□	□	–	□	–	□	–
Troy	39,419	□	–	–	–	–	–	–	–
Warren	179,260	□	■	□	–	–	–	–	–
Westland	86,749	■	■	–	–	–	–	–	–
Wyoming	56,560	□	–	–	–	–	–	–	–
MINNESOTA									
Bloomington	81,970	□	■	□	■	–	–	□	–
Brooklyn Park	13,692	■	■	■	■	–	–	–	–
Cannon Falls	2,155	–	–	■	–	–	–	–	–
Columbia Heights	23,837	–	■	–	–	–	–	–	–
Gilman	798	□	–	–	–	–	–	–	–
Minneapolis	434,400	□	■	■	–	–	–	■	□

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
Rochester	53.766	□	■	–	–	–	–	–	–
St. Paul	309 828	□	–	–	–	–	–	–	–
MISSISSIPPI									
Jackson	153.968	□	–	–	–	–	–	–	–
MISSOURI									
Bridgeton	19.992	□	–	–	–	–	–	–	–
Gladstone	23.422	□	–	■	–	–	–	■	–
Grandview	17.456	□	–	□	–	–	–	□	–
Independence	111.662	□	■	□	–	–	–	–	–
Kansas City	507 330	□	■	■	–	–	–	–	–
St. Louis	622.236	□	■	■	□	–	–	■	–
Springfield	120.096	□	–	□	–	–	–	–	–
Waynesville	3.376	□	–	□	–	–	–	–	–
MONTANA									
Billings	61.581	□	–	–	–	–	–	–	–
Great Falls	60.091	□	■	■	■	■	■	■	–
Helena	22.730	□	■	■	■	■	–	■	–
Livingston	6.883	□	–	–	–	–	–	–	–
Missoula	29.497	■	■	■	■	–	–	–	–
NEBRASKA									
Beatrice	12.787	□	–	–	–	–	–	–	–
Lincoln	149.518	–	–	■	–	–	–	–	–
McCook	8.285	□	■	■	–	■	–	–	–
Omaha	346.929	□	–	□	–	–	–	□	–
Scottsbluff	14.507	□	–	□	–	–	–	□	□
Sidney	6 258	□	–	□	–	–	–	–	–
NEVADA									
Las Vegas	125.787	□	■	□	–	–	–	–	–
NEW HAMPSHIRE									
Berlin	15.256	□	–	–	–	–	–	–	–
Concord	30.022	□	–	–	–	–	–	–	–
Manchester	87.754	□	–	–	–	–	–	–	–
NEW JERSEY									
Absecon	6.094	□	–	–	–	–	–	–	–
Asbury Park	16.533	□	–	–	–	–	–	–	–
Bayonne	72.743	□	–	–	–	–	–	–	–
Belleville	34 643	■	■	–	–	–	–	–	–
Berkeley Heights	13.078	■	■	–	–	–	–	■	■
Bloomfield	52 059	□	–	–	–	■	–	–	–
Boonton	9.261	■	■	–	–	–	–	–	–
Bordentown	4 490	□	–	–	–	–	–	–	–
Brigantine	6.741	□	–	–	–	–	–	–	–
Burlington	11 991	□	–	–	–	–	–	–	–
Camden	102 551	□	–	–	–	–	–	–	–
Cape May	4.392	□	–	–	–	–	–	–	–
Cedar Grove	15.582	■	■	–	–	–	–	–	–
Clifton	82.437	■	■	–	–	–	–	–	–
Clinton	1 742	□	–	–	–	–	–	–	–
Corbin	258	□	–	–	–	–	–	–	–
Dover	15.039	□	–	–	–	–	–	–	–
East Orange	75.471	□	–	–	–	–	–	–	–
Elizabeth	112.654	□	■	–	–	–	–	–	–
Ewing	32.831	□	–	–	–	–	–	–	–
Fairlawn	37 975	□	■	–	–	–	–	–	–
Gloucester	14.707	□	■	–	–	–	–	–	–
Hackensack	36.008	□	–	–	–	–	–	–	–
Hammonton	11.464	□	■	–	–	–	–	–	–
Hanover	10.700	–	■	–	–	–	–	–	–
Harrison	11.811	□	–	–	–	–	–	–	–
Hasbrouck Heights	13.551	□	–	–	–	–	–	–	–
Hawthorne	9.173	–	■	–	–	–	–	–	–
Hightstown	5.431	□	–	–	–	–	–	–	–
Hoboken	45.380	–	■	–	–	–	–	–	–
Irvington	59 743	–	■	–	–	–	–	–	–
Jersey City	260.545	□	–	□	–	–	–	–	–
Lakewood	17.874	□	■	–	–	–	■	□	–
Linden	41.409	□	–	□	–	–	–	□	–
Long Branch	31.774	□	–	–	–	–	–	–	–
Margate	10.576	□	–	–	–	–	–	–	–
Maywood	11.087	■	–	–	–	–	–	–	–
Morristown	17.662	□	–	–	–	–	–	–	–
Newark	382.417	□	–	–	–	–	–	–	–
Newton	7.297	□	–	–	–	–	–	–	–
North Haledon	7.614	□	–	–	–	–	–	–	–
North Wildwood	3.914	□	–	–	–	–	–	–	–
Nutley	31.913	□	–	–	–	–	–	–	–
Ocean City	10.575	□	–	–	–	–	–	–	–
Orange City	32.566	□	–	–	–	–	–	–	–
Passaic	55.124	□	–	–	–	–	–	–	–
Paterson	144.824	□	–	–	–	–	–	–	–
Pemberton Borough	1.576	□	–	–	–	–	–	–	–
Perth Amboy	38.798	□	–	–	–	–	–	–	–
Plainfield	46.862	□	–	–	–	–	–	–	–
Pleasantville	13.778	□	■	–	–	–	–	–	–
Princeton	12.311	■	■	–	–	–	–	–	–
Rahway	29.114	□	■	–	–	–	–	–	–
Ridgefield Park	14.453	□	–	–	–	–	–	–	–
Salem	7.648	□	–	–	–	–	–	–	–
Secaucus	13.228	□	–	–	–	–	–	–	–
South Amboy	9 338	□	■	–	–	–	–	□	–
Sparta	10.819	■	–	■	–	–	–	□	□
Summit	23.620	□	–	–	–	–	–	–	–
Trenton	104.638	□	–	–	–	–	–	–	–
Vineland	47.399	□	–	–	–	–	–	–	–
Wayne	49.141	□	–	–	–	–	–	–	–
Westfield	33.720	□	–	–	–	–	–	–	–
West Orange	43.915	■	■	■	■	–	–	–	–
Wharton	11.105	–	■	–	–	–	–	–	–
Wildwood	4.110	□	–	–	–	–	–	–	–
Woodbridge	78.846	■	–	–	–	–	–	–	–
NEW MEXICO									
Albuquerque	243.751	□	□	□	□	–	□	□	–
Gallup	13.779	□	–	□	–	–	–	–	–
Los Alamos	11.310	□	■	■	–	–	–	–	–
NEW YORK									
Albany	115.781	–	□	–	–	–	–	–	–
Auburn	34.599	–	■	–	–	–	–	–	–
Binghamton	64.123	–	■	–	–	–	–	–	–
Buchanan	2.110	–	■	–	–	–	–	–	–
Buffalo	462.768	□	–	□	–	–	–	–	–
Canandaigua	10.488	□	–	–	–	–	–	–	–
Clifton Springs	2.058	–	□	□	–	–	–	–	–
Corning	15.972	□	–	–	–	–	–	–	–
Cortland	19.621	–	■	–	–	–	–	–	–
Freeport	40.374	□	–	–	–	–	–	–	–
Geneva	16.763	□	–	–	–	–	–	–	–
Hammondsport	1.066	□	–	–	–	–	–	–	–
Hempstead	39.411	□	–	–	–	–	■	–	–
Hornell	12 144	□	–	–	–	–	–	–	–
Huntington	12.601	□	–	–	–	–	–	□	–
Islip	7.692	□	–	–	■	–	–	□	–
Ithaca	26.226	□	–	–	–	–	–	–	–
Lake George	1.506	□	□	–	–	–	–	–	–
Lynbrook	23.776	□	–	–	–	–	–	–	–
Lyons	4.496	□	–	□	–	–	–	–	–
Macedon	1.168	□	–	–	–	–	–	–	–
Mamaroneck	18.909	□	–	■	–	–	–	–	–
Marion	850		–	–	–	–	–	–	–
Montour Falls	1.534		–	–	–	–	–	–	–
New Rochelle	75.385		–	–	–	–	–	–	–
New York City	7.895.563		■	■	–	–	–	–	■
Niagara Falls	85.615		–	–	–	–	–	–	–
Niskayuna	6.186	–	■	–	–	–	–	–	–
Ossining	21.659	□	–	–	–	–	–	–	–
Penn Yan	5.168	□	–	–	–	–	–	–	–
Phelps	1.989	□	–	–	–	–	–	–	–
Rochester	296.233	□	–	–	–	–	–	–	–
Smithtown	12.000	■	–	□	–	–	–	□	–
Sodus	1.831	□	–	□	–	–	–	–	–
Southampton	4.904	□	–	–	–	–	–	–	–
Utica	91.611	□	–	–	–	–	–	–	–
Watkins Glen	2.716	□	–	–	–	–	–	–	–
White Plains	50.125	■	–	□	–	–	–	–	–
Williamstown	1.919	□	–	□	–	–	–	–	–
Wolcott	1.617	■	■	–	–	–	–	–	–
Wallkill	1.849	■	■	–	–	–	–	–	–
Yonkers	204.297	□	–	–	–	–	–	–	–
NORTH CAROLINA									
Aberdeen	1.592	□	–	–	–	–	–	–	–
Asheville	57.681	□	–	–	–	–	–	–	–
Aurora	620	□	–	–	–	–	–	–	–
Belmont	4.814	□	–	–	–	–	–	–	–
Benson	2.267	□	–	–	–	–	–	–	–
Boone	8.754	□	–	–	–	–	–	–	–
Burlington	35.930	□	–	–	–	–	–	–	–
Carolina Beach	1.663	□	–	–	–	–	–	–	–
Carrboro	3.472	□	–	–	–	–	–	–	–
Chapel Hill	25.537	■	■	□	–	–	–	□	–
Concord	18.464	□	–	–	–	–	–	–	–
Conetoe	160	□	–	–	–	–	–	–	–
Durham	95.438	□	–	□	–	–	–	□	–
Fayetteville	53.510	□	–	□	–	–	–	□	–
Forest City	7.179	□	–	–	–	–	–	–	–
Franklin	2.336	□	–	–	–	–	–	–	–
Fuquay-Varina	3.576	□	–	–	–	–	–	–	–
Gastonia	47.143	□	–	–	–	–	–	–	–
Gibsonville	2.019	□	–	–	–	–	–	–	–
Goldsboro	26.810	□	–	–	–	–	–	–	–
Greensboro	144.076	□	–	□	–	–	–	–	–
Hickory	20.569	□	–	–	–	–	–	–	–
High Point	63.204	□	–	–	–	–	–	–	–
Kings Mountain	8.405	□	–	–	–	–	–	–	–
Kinston	22.309	□	–	–	–	–	–	–	–
Kure Beach	394	□	–	–	–	–	–	–	–
Laurinburg	8.859	□	–	–	–	–	–	–	–
Lumberton	16.961	□	–	–	–	–	–	–	–
Madison	2.081	□	–	–	–	–	–	–	–
Manteo	547	□	–	–	–	–	–	–	–
Marion	3.335	□	–	–	–	–	–	–	–
Monroe	11.282	□	–	–	–	–	–	–	–
Mt. Pleasant	1.174	□	–	–	–	–	–	–	–
New Bern	14.660	□	–	□	–	–	–	–	–
Newton	7.857	□	–	–	–	–	–	–	–
Raleigh	123.793	□	–	□	–	–	–	–	–
Red Springs	3.383	□	–	–	–	–	–	–	–
Roanoke Rapids	13.508	□	–	–	–	–	–	–	–
Rocky Mount	34.284	□	–	–	–	–	–	–	–
Roper	649	□	–	–	–	–	–	–	–
Salisburg	22.515	□	–	–	–	–	–	–	–
Seaboard	611	□	–	–	–	–	–	–	–
Silver City	4.689	□	–	–	–	–	–	–	–
Southern Pines	5.937	□	–	–	–	–	–	–	–
Statesville	19.996	□	–	–	–	–	–	–	–
Tarboro	9.425	□	■	–	–	–	–	–	–
Thomasville	15.230	□	–	–	–	–	–	–	–

Jurisdiction	1970 Population	Nuisance	Zoning	Vehicle	Rec/Vehicle	Railroad	Aircraft	Construction	Building
Valdese	3,182	□	–	–	–	–	–	–	–
Wake Forest	3,148	□	–	–	–	–	–	–	–
Walnut Cove	1,213	□	–	–	–	–	–	–	–
Warsaw	2,701	□	–	–	–	–	–	–	–
Washington	8,961	□	–	–	–	–	–	–	–
Wilmington	46,169	□	–	–	–	–	–	–	–
Winston-Salem	132,913	□	■	■	–	–	–	–	–
Winton	917	□	–	–	–	–	–	–	–
NORTH OAKOTA									
Bismark	34,703	□	–	–	–	–	–	–	–
Minot	32,290	■	–	■	–	–	–	–	–
OHIO									
Akron	275,425	□	–	–	–	–	–	–	–
Amherst	9,902	□	–	–	□	–	–	–	–
Cincinnati	452,524	□	–	■	–	–	–	–	–
Cleveland	750,903	□	■	■	–	–	–	□	–
Columbus	540,025	□	■	–	–	–	–	–	–
Dayton	243,601	□	■	–	–	–	–	–	–
Mansfield	50,743	■	–	■	–	–	–	–	–
Middleburg Heights	12,367	–	■	■	■	■	–	–	■
Shaker Heights	36,306	□	–	■	–	–	–	–	–
Springfield	81,941	□	–	–	–	–	–	–	–
Toledo	383,818	□	■	■	■	–	–	■	–
University Heights	17,055	□	–	–	–	–	–	–	–
OKLAHOMA									
Oklahoma City	368,856	□	■	–	–	–	–	–	–
Tulsa	330,350	□	–	–	–	–	–	–	–
OREGON									
Albany	18,181	■	■	■	–	–	–	–	–
Ashland	12,342	□	–	□	–	–	–	–	–
Astoria	10,244	□	–	–	–	–	–	–	–
Beaverton	18,577	■	■	■	–	–	–	–	–
Bend	13,710	□	–	□	–	–	–	–	–
Bandon	1,832	□	–	□	–	–	–	–	–
Central Point	4,004	□	–	□	–	–	–	–	–
Coos Bay	13,466	□	–	□	–	–	–	□	–
Corvallis	35,153	□	–	–	–	–	–	–	–
Oallas City	10,423	□	–	□	–	–	–	□	–
Eugene	76,346	■	■	■	–	–	–	–	–
Grants Pass	12,455	□	■	–	–	–	–	–	–
Hillsboro	14,675	■	■	■	–	–	–	–	–
Klamath Falls	15,775	□	–	–	–	–	–	–	–
Lake Oswego	14,573	■	■	■	–	–	–	–	–
Medford	28,454	□	–	–	–	–	–	–	–
Milwaukie	16,379	□	–	□	–	–	–	–	–
Pendleton	13,197	□	–	–	–	–	–	–	–
Portland	380,620	□	■	■	■	–	–	■	–
Silverton	4,301	–	■	–	–	–	–	–	–
Toledo	2,818	□	–	–	–	–	–	–	–
Tualatin	768	□	–	–	–	–	–	–	–
Yachats	414	□	–	–	–	–	–	–	–
PENNSYLVANIA									
Allentown	109,527	■	■	■	–	–	■	–	–
Bethlehem	72,686	□	■	–	–	–	–	–	–
Oubois	10,112	□	–	–	–	–	–	–	–
Erie	129,231	□	–	–	–	–	–	–	–
Girard	2,631	–	■	–	–	–	–	–	–
Harrisburg	68,061	■	■	■	■	–	–	–	–
Muhlenberg Township	5,212	□	–	–	–	–	–	–	–
Philadelphia	1,950,098	□	–	–	–	–	–	–	–
Pittsburgh	520,117	□	–	–	–	–	–	–	–
Scranton	103,564	□	–	–	–	–	–	–	–
State College	33,778	■	–	■	–	–	–	–	–
West Mifflin	28,070	□	■	–	–	–	–	–	–
RHOOE ISLAND									
Cranston	74,287	–	■	–	–	–	–	–	–
East Providence	48,151	–	■	–	–	–	–	–	–
Pawtucket	76,984	■	■	–	–	–	–	■	■
Providence	179,116	□	–	–	–	–	–	–	–
Warwick	83,694	–	■	–	–	–	–	–	–
SOUTH CAROLINA									
Columbia	113,542	–	■	■	–	–	■	–	–
Florence	25,997	–	■	–	–	–	–	–	–
SOUTH OAKOTA									
Lammon	2,456	–	–	■	–	–	–	–	–
Sioux Falls	72,488	–	□	□	–	–	–	–	–
TENNESSEE									
Chattanooga	119,923	□	–	□	–	–	–	□	–
Kingsport	31,939	□	–	□	–	□	–	–	–
Knoxville	276,293	–	–	■	■	–	–	□	–
Memphis	623,530	□	–	□	–	–	–	□	–
Nashville	448,003	–	■	□	–	–	–	–	–
TEXAS									
Amarillo	127,010	□	■	■	–	–	–	–	–
Austin	193,862	□	–	–	–	–	–	–	–
Beaumont	117,548	□	–	–	–	–	–	□	–
Corpus Christi	204,525	□	–	□	–	–	–	–	–
Oallas	844,401	□	■	–	–	–	–	–	–
El Paso	322,261	□	–	□	–	–	–	–	–
Fort Worth	393,476	□	–	□	–	□	–	–	–
Garland	81,437	□	–	□	–	–	–	–	–
Houston	1,232,802	□	–	–	–	–	–	–	–
Irving	97,457	□	–	□	–	–	–	□	–
Killen	35,507	□	–	□	–	–	–	–	–
Mineral Wells	18,411	□	–	□	–	–	–	–	–
Odessa	78,380	□	■	□	–	□	□	□	–
Saginaw	2,382	□	–	□	–	–	–	□	–
San Antonio	654,153	□	–	–	–	–	–	–	–
Texarkana	30,497	□	–	□	–	–	–	□	–
Wichita Falls	96,265	□	–	□	–	–	–	□	–
UTAH									
Murray	21,206	■	–	■	–	–	–	–	–
Ogden	69,478	■	■	■	–	–	–	■	–
Provo	53,131	■	–	■	–	–	–	■	■
Roosevelt	2,005	□	–	–	–	–	–	–	–
Salt Lake City	175,885	■	■	■	■	■	–	■	–
VIRGINIA									
Alexandria	110,927	■	■	■	–	–	–	–	–
Arlington	174,284	□	■	■	–	–	–	–	–
Chesapeake	89,580	□	□	–	–	–	–	–	–
Fairfax	21,970	–	■	–	–	–	–	–	–
Hampton	120,779	□	□	□	□	–	–	□	–
Newport News	138,177	■	■	–	–	–	–	–	–
Norfolk	307,951	□	–	□	–	–	–	□	–
Richmond	249,621	□	□	–	–	–	–	–	–
Roanoke	92,115	■	■	–	–	–	–	–	–
Virginia Beach	172,106	–	■	–	–	–	–	–	–
WASHINGTON									
Bellevue	61,102	–	■	–	–	–	–	–	–
Cheney	6,718	■	■	–	–	–	–	–	–
Colfax	2,664	■	■	■	■	□	□	–	–
College Place	4,510	□	–	■	–	–	–	–	–
Kennewick	15,212	■	■	■	■	□	□	□	□
Medina	3,455	■	–	■	–	–	–	■	–
Pullman	20,509	■	■	□	–	–	–	□	–
Renton	25,878	–	■	□	□	□	□	–	–
Richland	26,290	–	■	–	–	–	–	–	–
Seattle	530,831	□	–	■	–	–	–	–	–
Snohomish	5,174	■	■	■	–	–	■	–	–
Spokane	170,516	□	□	–	–	–	–	–	–
Tacoma	154,581	–	■	–	–	–	–	–	■
Walla Walla	23,619	□	–	□	□	□	–	□	–
Yakima	45,588	□	–	□	–	–	–	□	–
WISCONSIN									
Janesville	46,426	□	–	–	–	–	–	–	–
Madison	173,258	■	■	□	–	–	–	–	–
Milwaukee	717,372	■	■	■	–	–	–	–	–
Racine	95,162	■	■	–	–	–	–	–	–
Sparta	6,258	□	–	□	–	–	–	–	–
WYOMING									
Casper	39,361	–	□	–	–	–	–	–	–
Cheyenne	40,914	■	–	■	–	–	–	–	–
Lander	7,112	□	–	■	–	–	–	–	–
Powell	4,807	□	–	■	–	–	–	–	–
Riverton	7,995	–	–	■	–	–	–	–	–
Worland	5,055	□	–	–	–	–	–	–	–
Total	**67,383,478**								

are referred to as performance type regulations while those without noise emission limits are non-quantitative and difficult to enforce. Interest in regulating land use through the zoning process remains the largest single legal category of noise control. However, vehicular, aircraft and building controls with quantitative noise emission limits also have grown over the previous year." [33]

2.4.4.2. State Regulatory Efforts

"Recently more States have been entering the noise control field. Some State legislation specifically regulates noise, whereas most assign the environmental departments the task of studying and promulgating regulations.

"California's law governing airport noise became effective December 1, 1971. The law requires operators of existing airports to monitor the noise of aircraft on takeoffs and landings and to establish a Noise Impact Boundary around the airport with noise at this boundary to be reduced periodically over the next fifteen years. New airports must conform to the standards applicable (in fifteen years) to existing airports. The airport operator must also set noise limits on single takeoffs and landings. Those airports which fail to come within the noise limits may lose their licenses or face other State sanctions. California has attempted to avoid constitutional difficulties by basing its legislation on the State's licensing power over airports and the proprietary rights of airports vis-a-vis the scheduled airlines and other users. The practical difficulty with this law is that it may require airport operators to curtail operations or to make major purchases of land. The former measure could have major repercussions for national air transportation patterns, while the latter alternative could lie well beyond the financial capacity of the airport.

"The bi-State Port of New York Authority has set an objective noise limit of 112 PNdB for takeoffs from its four airports. This limit is very high, however, and there is also alleged to be systematic cheating by aircraft momentarily cutting power as they pass the monitoring equipment.

"Almost all States have laws governing motor vehicles, most requiring mufflers, some restricting unnecessary use of automobile horns. Increasing numbers of states are setting noise level limits on vehicle operation and, in some cases, on new vehicles. States also provide quantitative standards on motorcycles and in increasing numbers, on snowmobiles as well.

"Colorado alone sets limits on noise radiating from construction sites and few States have any requirement concerning the acoustical treatment of buildings. The regulation at the State level of noise from commercial sources is negligible. Many states do prohibit disturbances of the peace." [32]

An adequate current review of state noise regulatory efforts is not to be found within the literature, although preliminary response to inquiries indicates an increasing degree of concern on the part of state governments.

2.4.4.3. Federal Regulatory Efforts

"The Noise Pollution and Abatement Act of 1970 was the first legislation to provide a central focus to environmental noise abatement at the Federal level. This act provided for an Office of Noise Abatement and Control to be established in the Environmental Protection Agency for the purpose of carrying on research and investigations into the environmental noise problem. §402(c) of the act also requires any Federal agency whose activity is creating noise amounting to a public nuisance to consult with EPA to determine possible ways to abate such noise.

"The National Environmental Policy Act of 1969 has required since January 1, 1970, that Federal agencies submit environmental impact statements on all Federal actions significantly affecting the quality of the human environment. These statements should include the noise impact of the proposed action.

"The 1968 amendment (§611 -- Abatement of Aircraft Noise and Sonic Boom) to the Federal Aviation Act of 1958 was the beginning of the Federal government's active participation in the aircraft noise abatement area, Part 36 of the FAA Aircraft regulations, effective December 1, 1969, and issued pursuant to this legislation, requires all new subsonic aircraft to conform to specified noise levels on takeoff and landing before issuance of type certification.

"The first active consideration of highway noise at the Federal level was Policy and Procedures Memorandum 20-8 of the Bureau of Public Roads, issued January 14, 1969.... Pursuant to a 1970 amendment to the Federal-aid Highway Act, the Secretary of Transportation... is to develop and promulgate standards for highway noise levels compatible with different land uses after July 1, 1972.

"Regulations of May 20, 1969, pursuant to the Walsh-Healey Public Contracts Act, set noise exposure limits for employees of Federal supply contractors. With the enactment of the Occupational Health and Safety Act of 1970 these standards were applied to all business affecting interstate commerce, with the provision that any State may take over regulation of occupational noise with the approval of the Secretary of Labor. Civil and criminal penalties for violations are provided. The Bureau of Mines of the Department of the Interior applies the standards to some 1,900 licensed mines pursuant to the Federal Coal Mine Health and Safety Act of 1969.

"Pursuant to the Construction Safety Act of 1969 the Walsh-Healey noise standards have been applied to Federal construction projects by the Department of Labor." [32]

At the time of this writing (March 1975), the Occupational Safety and Health Administration has proposed retention of the 90 dB A-weighted limit for an eight hour exposure to industrial noise, with, however, some changes in the earlier provisions. The Environmental Protection Agency has advocated adoption of more stringent noise exposure criteria, and in particular has suggested an A-weighted sound level of 85 dB as a more acceptable limit for an 8-hour exposure. These differences of proposed policy are undergoing discussion.

"In the area of the acoustical characteristics of buildings, the Department of Housing and Urban Development has issued Policy Circular 1390.2 (August 4, 1971), concerning the acoustical acceptability of new sites and existing buildings to be aided by HUD funds. The noise limits involved relate to programs of mortgage underwriting in noisy areas near airports and minimum standards for multifamily dwellings for which HUD financial assistance is sought.

"On October 27, 1972, the President signed into law the Noise Control Act of 1972. With this legislation the Environmental Protection Agency (EPA) has significant authority to deal with numerous noise sources for the first time. The Administrator of the EPA is authorized to promulgate noise emission standards for construction equipment, transportation equipment (including recreational vehicles), any motor or engine (including any equipment of which an engine or motor is an integral part), electrical or electronic equipment, railroads and motor carriers. EPA is also to assume an important role in the development of aircraft noise standards. The new legislation clearly provides EPA with considerable authority to deal with the nation's present noise problems." [32]

In most of the aforementioned legislation, NBS provided comments to Congressional committees prior to the time the legislation was voted on by the Congress, and has assisted the responsible agencies in implementing the legislation (e.g., development of measurement methodologies, standards review).

The preceding material also is cited in order to indicate that there is an appreciable amount of activity involving local, state, and Federal regulatory agencies. The inter-relationships of these agencies is discussed in Appendix C, which is an edited survey of an oral presentation on government standards and regulations.

2.4.4.4. Quasi-Governmental Regulatory Units

There are few of these units in acoustics, with the possible exception of the American National Standards Institute. The relationship of this institute to standardization institutions and in the acoustical measurement infrastructure is discussed in Sections 2.2.1.1.1. and 2.2.1.1.3.

2.5. Direct Measurements Transactions Matrix

2.5.1. Analysis of Suppliers and Users

The summary input-output matrix contained within this section is based upon identification of 18 institutional elements, which serve dual roles in the measurement infrastructure as suppliers and users. These eighteen elements are:

1. *Knowledge Community:* Scientific organizations, the general scientific community; academic institutions (elementary and secondary schools, colleges and universities, vocational training institutions), libraries, information centers; domestic and international professional, scientific and technical societies; technical publishing houses; and the like.

2. *International Metrological Organizations:* International Bureau of Weights and Measures (BIPM). International Organization for Legal Metrology (OIML).

3. *Documentary Standardization Organization:* American National Standards Institute (ANSI) and American Society for Testing and Materials (ASTM) and their affiliated organizations. International Organization for Standardization (ISO) and International Electrotechnical Commission (IEC). The national physical standards laboratories and services of other nations. The documentary standardization committees of domestic and international professional, scientific, technical, and industrial trade organizations. The standardization activities of the U. S. Department of Defense.

4. *Instrumentation Industry:* Instruments and related products-- engineering and scientific instruments, environmental controls, process control instruments, other measuring and controlling devices.

5. *National Bureau of Standards:* The National Bureau of Standards -- all Institutes and divisions.

6. *Other U. S. National Standards Authorities:* Only three such organizations have been identified -- The U. S. Naval Observatory (USNO) in the field of time-keeping (time and frequency); The U. S. Geological Survey in aerial camera calibration (optics); The U. S. Coast Guard for measurements related to sea transportation of liquified natural gas. These have little relevance to this particular study.

7. *State and Local Offices of Weights and Measures (OWM's):* The state, county, and city or similar agencies responsible for policing the honesty of weights and measures practices in commercial transactions. These have little relevance to this particular study.

8. *Standards and Testing Laboratories and Services:* Members of the National Conference of Standards Laboratories and organizations eligible for such membership. Testing laboratories such as Underwriters' Laboratories and the many commercial analytical laboratories. Note also that all standards laboratories and organizationally distinct testing laboratories are included in this sector, no matter in what larger organization they may be embedded. Thus, the standards laboratory structure of the Department of Defence is covered here, and the standards laboratories of the major economic industrial sectors.

9. *Regulatory Agencies (excluding OWM's):* Federal, state, and local government regulatory agencies, excluding those units which regulate the commercial weights and measures field or which perform classical policing or law-enforcement duties, or the normal legislative branches of government. Examples at the Federal level include the Bureau of Mines, Consumer Product Safety Commission, Environmental Protection Agency, National Highway Traffic Safety Administration, and the Occupational Safety and Health Administration. On the local level, similar agencies are active primarily in the public health field, in occupational safety and health, and in enforcing environmental protection regulations. While the presumption is that all of these agencies are governmental, there may be instances of private or quasi-governmental agencies that fall in this sector.

10. *Department of Defense (excluding standards labs.):* The Air Force, Army, Navy, Advanced Research Projects Agency, Defense Nuclear Agency, Defense Supply Agency and <u>all</u> intelligence and security agencies.

11. *Civilian Federal Government Agencies:* Congress and its agencies. Judicial branch. Executive Office of the President. Depts. of Agriculture, Housing and Urban Development, Interior, Justice, Labor, State, and Treasury. Dept. of Commerce, excluding NBS, but including the National Oceanic and Atmospheric Admin. (and therefore the National Weather Service and National Ocean Survey), Patent Office, and Office of Telecommunications. Dept. of Health, Education and Welfare, including the National Institutes of Health, and National Institute for Occupational Safety and Health. Dept. of Transportation, including the Coast Guard and Federal Aviation Admin., Energy Research and Development Admin.,

General Services Admin., National Aeronautics and Space Admin., National Science Foundation, Tennessee Valley Authority, U. S. Arms Control and Disarmament Agency, U. S. Information Agency, U. S. Postal Service, and Veterans Admin.

12. *State and Local Government Agencies:* All aspects of state and local governments, with some major exclusions -- Public schools, colleges and universities; Offices of Weights and Measures; Regulatory agencies; Public health departments and publicly run hospitals. All these groups are covered in other sectors.

13. *Industrial Trade Associations:* Industrial, business, or trade associations, such as the Electric Power Research Institute (ERPI), the Electronic Industries Assn. (EIA), the Motor Vehicle Manufacturers Assn. (MVMA), the Air Conditioning and Refrigeration Institute (ARI), and the Compressed Air and Gas Institute (CAGI).

14. *Extractive Industry:* Crops. Livestock. Agricultural services, including landscape and horticultural services. Forestry. Mining. Coal mining. Oil and gas extraction. Stone, gravel, clay, chemical, and fertilizer minerals.

15. *Construction:* General building contractors. Heavy construction contractors. Special trade contractors--plumbing, heating, air conditioning, electrical, water well drilling, etc. Note that engineering and architectural services relevant to this sector are included here.

16. *Food/Tobacco/Textile/Apparel/Lumber/Furniture/Paper/Leather:* Food and kindred products. Tobacco manufacturers. Textile mill products--weaving, knitting, floor covering, and yarn and thread mills; tire cord and fabric cordage and twine. Apparel and other textile products. Lumber and wood products--logging camps, sawmills, mobile homes, prefabricated wood buildings. Furniture and fixtures: drapery hardware, blinds and shades. Paper and allied products--pulp and paper mills, building paper and board. Leather and leather products--tanning and finishing, footwear (except rubber).

17. *Chemicals/Petroleum/Rubber/Plastics/Stone/Clay/Glass:* Chemicals and allied products. Petroleum and coal products--petroleum refining, paving and roofing materials. Rubber and miscellaneous plastics products--tires, footwear, miscellaneous plastics products. Stone, clay and glass products --flat glass, cement, structural clay products, vitreous plumbing fixtures, block and related products, lime, gypsum products, stone.

18. *Primary and Fabricated Metal Products:* Primary metal industries--iron and steel, nonferrous metals, plate, sheet. Fabricated metal products--heating equipment, household furnace humidifiers, structural metal, doors, prefabricated metal buildings.

19. *Machinery, except Electrical:* Turbines, turbine generators, internal combustion engines; farm, lawn, garden, construction, mining, oil field, rolling mill, metalworking, food products, textile, woodworking, paper industries and printing trades machinery; industrial trucks and tractors; pumps, compressors, blowers, fans; speed changers, drives, and gears; typewriters, electronic computing equipment, calculating and accounting machines; commercial laundry, refrigeration and heating equipment; humidifying equipment, except household furnace or room electric; carburetors, pistons, rings, and valves.

20. *Electrical and Electronic Equipment:* Transformers, motors, and generators, refrigerators and freezers, electric humidifiers, laundry equipment, vacuum cleaners, sewing machines, small electrical appliances; radio and TV sets, phonograph records, telephone and telegraph apparatus, radio and TV communication equipment.

21. *Transportation Equipment:* Motor vehicles, aircraft, ships, boats, railroad equipment, motorcycles.

22. *Transportation and Public Utilities:* Railroad transportation. Local and interurban passenger transit, including taxicabs and school buses. Trucking and warehousing. Water transportation. Air transportation. Transportation services. Communication--telephone, telegraph, radio and TV broadcasting, other communication services.

23. *Trade (Retail and Wholesale)/Insurance/Finance/Real Estate/Personal Services/Printing and Publishing:* Wholesale Trade--autos, construction materials, electrical apparatus and appliances, TV and radio, electronic equipment, heating and air conditioning, refrigeration, industrial machinery, transportation equipment. Retail Trade--building materials. Finance, Insurance and Real Estate. Services (other)--radio and TV, motion pictures from production through theaters. Printing and Publishing--commercial printing; photo-engraving and related printing and publishing services.

24. *Health Services:* Offices of physicians, dentists, osteopathic physicians, chiropractors, optometrists; nursing and personal care facilities; hospitals; medical and dental laboratories; outpatient care facilities, other health and allied services.

25. *General Public:* The person-on-the-street, housewife, automobile driver, private pilot, amateur radio operator, home do-it-yourselfer, camper, amateur sportsman; the worker as a private person on the job, being exposed to job safety and health hazards. The consumer, consumer advocate, public interest advocate, citizen taxpayer. End users of most data, but frequently only in an indirect manner in this field.

The various relevant measurement capabilities and services offered by the eighteen suppliers are given in table 6, along with the needs of these same sectors as users and the services they procure.

2.5.2. Direct Measurements Transactions Matrix

The direct measurements transaction matrix, figure 7, indicates several dimensions of the transactions occurring between the several suppliers and users. Within each matrix element there may be as many as five symbolic entries denoting the several dimensions of the transaction. The coding for four of these is consistent among all of the measurement system studies in this series, and is described in the key at the bottom of the table.

The alphabetic symbol in the lower right hand corner describes the type of provision of service in the direct measurement transaction.

A. End-use Measurement Data
B. Other Measurement Services (e.g., calibrations)
C. Measurement Instrumentation and Associated Software
D. Measurement "How To" Information
E. Measurement "Needs" Information

The appearance of only one symbol in any transactions box (that for the primary magnitude quantity) implies that NBS' knowledge is insufficient to support an estimate of the subsidiary information items. An empty box indicates that the volume of transactions is judged to be negligible. If one or more of the corners have symbols entered, then those that are still blank can be read as zeros.

2.5.3. Highlights re Major Users

The majority of the users of the acoustical products listed in table 3 fall into the groups identified in table 7. Additional more specific noise abatement products can be identified; however, the group becomes so large that much of our present day industrial technology can be included. For example, manufacturers of business machinery purchase vibration damping products to implement noise control measures directed toward the control of related structure-borne vibrations. Yet they may not attempt to quantitatively measure the mechanical properties of the vibration damping product. They may instead elect to judge the product's effectiveness through measurement of the reduction of radiated noise, an acoustical measure of the effectiveness of a vibration damping product. To implement this evaluation of a vibration control product, they thus require instrumentation to perform the acoustical measurement. There are numerous similar identifiable examples which could be cited, and a large segment of current technology ultimately becomes involved.

Table 6. Measurement capabilities and services supplied, needs and services procured, by acoustics measurement systems sectors.

	Suppliers	Measurement Capabilities	Services Provided	Measurement Needs	Services Procured
1.	Knowledge Community	Basic physical research, many acoustical measurements	Dissemination of knowledge, standards committees evolve standards, consultant services	Measurement data	Information on measurement methodologies, measurement data, publications, etc.
2.	International Metrological Organizations	(None specific)	Measurement methodology, development of instrumentation systems, calibration services, provision of data base, etc.	Measurement data, calibration data	Information on measurement needs, instrumentation, information on measurement methodology
3.	Documentary Standardization Organizations	No measurement capabilities, *per se*	Evolve measurement methodologies, disseminate same.	(None specific)	Measurement data, information on methodologies
4.	Instrumentation Industry	Acoustical measurements required for product development	Provide measurement instrumentation, calibration services	Measurement data	Calibration services, measurement needs information
5.	National Bureau of Standards	Wide range of acoustical measurements and basic research	Measurement methodology, development of instruumentation systems, calibration services, provision of data base, etc.	Measurement data, calibration data	Information on measurement needs, instrumentation information on measurement methodology
6.	Other U. S. National Standards Authorities	(None specific)	(None specific)	(None specific)	(None specific)
7.	State and Local Offices of Weights and Measures	(None specific)	(None specific)	(None specific)	(None specific)
8.	Standards and Testing Laboratories and Services	Wide range of acoustical measurements	Measurement data, calibration services, etc.	Measurement data, calibration data	Information on measurement needs, instrumentation information on measurement methodology
9.	Regulatory Agencies (excluding OWM's)	Noise emission monitoring, environmental noise monitoring	Measurement data, measurement methodologies, etc.	Information on measurement methodology, measurement data	Measurement data, instrumentation, information on measurement methodology and on measurement needs
10.	Department of Defense (excluding standards labs)	(Largely excluded from study)	(Largely excluded from study)	Measurement data	Measurement data, instrumentation
11.	Civilian Federal Government Agencies	Acoustical measurements in research (e.g., NASA)	Measurement needs information, measurement data, etc.	Information on measurement methodology, measurement data	Measurement data, instrumentation, information on measurement methodology and on measurement needs
12.	State and Local Government Agencies	Noise emission or environmental noise monitoring	Measurement data, measurement methodologies	Information on measurement methodology, measurement data	Measurement data, instrumentation, information on measurement methodology and on measurement needs
13.	Industrial Trade Associations	No measurement capabilities, *per se* at the trade association level. More within relevant industry	Measurement data, measurement needs information, etc.	Measurement data, measurement needs	Measurement data
14.	Extractive Industry: Agriculture, Mining, etc.	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data
15.	Construction	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data
16.	Food/Tobacco/Textile/ Apparel/Lumber/Furniture/ Paper/Leather	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data

Table 6 (Continued)

	Suppliers	Measurement Capabilities	Services Provided	Measurement Needs	Services Procured
17.	Chem./Petro./Rubber/ Plastic/Stone/Clay/Glass	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data
18.	Primary and Fabricated Metal Products	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data
19.	Machinery except Electrical	Noise emission monitoring, environmental noise monitoring	Product noise data	Information on measurement methodology, measurement data, calibration data	Measurement data
20.	Electrical and Electronic Equipment	Noise emission monitoring, environmental noise monitoring	Specifications re: instrumentation response	Information on measurement methodology, measurement data, calibration data	Measurement data
21.	Transportation Equipment	Noise emission monitoring, environmental noise monitoring	Product noise data, measurement procedures	Information on measurement methodology, measurement data, calibration data	Measurement data
22.	Transportation and Public Utilities	Noise emission monitoring, environmental noise monitoring	(None specific)	Information on measurement methodology, measurement data, calibration data	Measurement data
23.	Trade/ Ins./ Fin./ Real Estate/ Pers. Svcs./ Print., Pub.	(None specific)	(None specific)	(None specific)	(None specific)
24.	Health Services	Medical diagnostic data	Medical diagnostic and therapeutic services	Information on instrumentation performance	Instrumentation and calibration services
25.	General Public	Very little measurement capability	Measurement needs information	Measurement data	Measurement methodology information

DIRECT MEASUREMENTS TRANSACTIONS MATRIX FOR ACOUSTICS — SUPPLIERS \ USERS	1 KNOWLEDGE COMMUNITY (Science Educ Prof Soc & Publ)	2 INTERNATIONAL METROLOGICAL ORGANIZATIONS	3 DOCUMENTARY STANDARDS ORGANIZATIONS	4 INSTRUMENTATION INDUSTRY (SIC Major Gp 38)	5 N B S	6 OTHER U S NATIONAL STANDARDS AUTHORITIES	7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES	8 STANDARDS & TESTING LABORATORIES AND SERVICES	9 REGULATORY AGENCIES (excl OWM s)	10 DEPARTMENT OF DEFENSE (excl Std Labs)	11 CIVILIAN FEDERAL GOVERNMENT AGENCIES	12 STATE AND LOCAL GOVERNMENT AGENCIES	13 INDUSTRIAL TRADE ASSOCIATIONS	14 EXTRACTIVE IND AG MINING ETC (SIC Div A&B)	15 CONSTRUCTION (SIC Div C)	16 FOOD TEXTILE LBR PAPER LEATHER ETC (SIC 20 26 31)	17 CHEM PETROL RUBBER STONE CLAY GLASS (SIC 28 30 32)	18 PRIMARY & FAB METAL PRODUCTS (SIC 33 34 391)	19 MACHINERY EXCEPT ELECTRICAL (SIC Major Gp 35)	20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	22 TRANSPORTATION & PUBLIC UTILITIES (SIC Div E)	23 TRADE INS FIN REAL EST PERS SVCS PRINT (SIC F H bal I 27)	24 HEALTH SERVICES (SIC Major Gp 80)	25 GENERAL PUBLIC
1 KNOWLEDGE COMMUNITY (Science Educ (Prof Soc & Publ)	2 1 / 3 / 2		2 1 / 3	1 1 / 2 / 2	2 1 / 3			2	2	X	2		1	1	3	2	2	2	3	3	3	2		3	1
2 INTERNATIONAL METROLOGICAL ORGANIZATIONS																									
3 DOCUMENTARY STANDARDIZATION ORGANIZATIONS	1		2 2 / 3 / 2	2 1 / 3 / 1	2 2 / 4 / 2			2 1 / 3	2 3 / 2 / 2	X	2		3 2 / 3 / 2	1	2 1 / 4	1	1	1	2	3	2 1 / 4	1		3	
4 INSTRUMENTATION INDUSTRY (SIC Major Gp 38)	2 1 / 3 / 1		2 1 / 2 / 2	2 / 3 / 2	2 1 / 3 / 2			3 2 / 3 / 2	2	3 1 / 4 / 3	2 1 / 3 / 2		2 1 / 3 / 2	3	3	3	3	3	3	3	3	2		3	1
5 NBS	2 2 / 2 / N		2 1 / 3 / 1	2 1 / 3 / 4	2 1 / 3 / 2			2 1 / 2 / 1	3 3 / 4 / 1	2 / 1 / 2	2 / 3	2	3 2 / 3 / 1		2		1			2	2 1 / 3 / 2			2 3 / 1 / 2	2
6 OTHER U S NATIONAL STANDARDS AUTHORITIES																									
7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES																									
8 STANDARDS & TESTING LABORATORIES AND SERVICES	1		3	2 1 / 3 / 2	2 1 / 2			1 / 2	2 1 / 4 / 2	X	2		3 / 4 / 2	2	3	3	3	3	2	2	3	2	1	1	1
9 REGULATORY AGENCIES (excl OWM s)	1		1	2	3 3 / 3 / 1			3 1 / 3 / 2	3 3 / 4 / 1	X	2		3 1 / 4 / 3	4 2 / 4	4 1 / 3 / 2	4 2 / 4	2	2	4 1 / 4 / 2	2	4 1 / 4 / 2	4 1 / 3 / 2	1	4 3 / 3 / 4	3 2 / 3 / 4
10 DEPARTMENT OF DEFENSE (excl Stds Labs)	X		1	2 2 / 3 / 2	X			X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
11 CIVILIAN FEDERAL GOVERNMENT AGENCIES			2	2 1 / 3 / 1	2 / 3			2	1	X	3 3 / 2		3 1 / 2 / 2												3 1 / 3 / 2
12 STATE & LOCAL GOVERNMENT AGENCIES	1				1			2	1	X		2		1	1	1	1	1	1	1	1	1	1		2
13 INDUSTRIAL TRADE ASSOCIATIONS	1		2 2 / 3 / 2	2 1 / 3 / 2	2 1 / 4 / 1			3 1 / 3 / 2	2 1 / 4 / 2	X	2		2 1 / 3 / 2	1	1	1	1	1	1	1	1				2
14 EXTRACTIVE IND AG MINING ETC (SIC Div A&B)				2	1			1	2	X				2								1			
15 CONSTRUCTION (SIC Div C)	2 / 3		3	2	3			3	3	2	2		2	2	2 1 / 3 / 2						1				3
16 FOOD TOB TEXTILE APPAREL LBR FURN PAPER LEATHER (SIC 20 26 31)	2							2	3 1 / 3 / 2	X	1	2	2			2			2						
17 CHEM PETROL RUBBER PLASTICS STONE CLAY GLASS (SIC 28 30 32)				2				2	3	X		2	2				2								1
18 PRIMARY & FAB METAL PRODUCTS (SIC 33 34 391)	1							2	3	X		2	2					2	2	2					1
19 MACHINERY EXCEPT ELECTRICAL (SIC Major Gp 35)	2		4 1 / 3 / 0	2	3			2	2 1 / 4 / 2	X	2	2	2	2	2	2	2	2	2 1 / 3 / 2	2	2	2			2
20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	1		2		2			2	1	X		1	2							3					2
21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	2		3	1	2 1 / 2 / 2				3 1 / 3 / 2	X		3 1 / 3 / 2	4 / 4	1	1	1	1	1	1	1	2 1 / 2	1			2
22 TRANSPORTATION PUBLIC UTILITIES (SIC Div E)	2				3			2	3 1 / 3 / 2	X		3	3								2	2			2
23 TRADE INS FIN REAL EST PERS SVCS PRINT PUB (SIC F H bal I 27)																							1		
24 HEALTH SERVICES (SIC Major Gp 80)	2		1	3	2			2	2	X	2	2		1	1	1	1	1	1	1	1	1		2	1
25 GENERAL PUBLIC	1				1			1	1 / 3 / 2	X	2		2 1 / 2 / 2												1

KEY TO MATRIX ENTRIES

C — IMPORTANCE OF TRANSACTIONS
- 1 = Purely convenience
- 2 = Strongly desirable
- 3 = No real alternatives
- 4 = Essential

B — RATE OF CHANGE
- N = Declining
- 0 = Stable
- 2 = Growing
- 4 = Growing explosively

	USERS	
SUPPLIERS	C	D
	A	
	B	

D — (IN)ADEQUACY OF SERVICES
- 0 = No improvements needed
- 1 = Could be improved
- 2 = Marginal
- 3 = Serious deficiencies
- 4 = Out of control

A — MAGNITUDE OF TRANSACTIONS
- 0 = Trivial
- 1 = Minor
- 2 = Moderate
- 3 = Important
- 4 = Major

? = Unknown, X = Not studied, Blank = 0

Figure 7. Acoustical measurement system input-output direct transactions matrix.

Table 7. Users of acoustical measurement instrumentation.

- --- Manufacturers and Users of "Noisy" Products
- --- Manufacturers and Users of Noise Abatement Products
- --- Federal, State, and Local Regulatory Agencies
- --- Environmental Control Engineers in Industrial Plants
- --- Research Scientists and Engineers in
  - Industrial Laboratories
  - Independent Research Institutions
  - Government Laboratories
  - Academic Laboratories
- --- Independent Testing Laboratories
- --- Architects and Urban Design Engineers
- --- Acoustical Consultants

3. IMPACT, STATUS AND TRENDS OF THE MEASUREMENT SYSTEM

3.1. Impact of Measurements

3.1.1. Functional, Technological and Scientific Applications

3.1.1.1. Use and Function of the Measurements

The preceding sections have described a number of acoustical measurement processes which are related to the unifying theme of accomplishing an adequate, objective, quantitative characterization of sound or acoustical properties. By implication it may appear that the principal utility of these measurements is for the implementation of noise control legislative or abatement measures, but this is not strictly the case. Acoustics is a scientific discipline with relevance to many aspects of man's existence. Many of these aspects have grown phenomenally without explicit appreciation of the importance of acoustical phenomena. For example, it was only as recently as the 1930's that the fundamental physical phenomena involved in airborne sound transmission through walls and partitions was studied in any detail. [36] Pioneering work of Buckingham [34], Chrisler and Snyder [35], and London [36] at NBS led to the evolution of a quantitative single-figure rating system [19] to evaluate this property of building system components. Prior to that time, architects were only able to rely upon crude empirical rules in order to provide desired acoustical properties -- rules that were often inadequate to the challenge.

It was also shown that acoustics is used for the improvement of communication systems, for entertainment and aesthetic purposes, and for numerous other purposes, including the implementation of noise control measures. Acoustical measurements are required for the evaluation of design changes and within research and development programs dealing with devices such as communication system components (e.g., telephone transmitter microphones and receiver earphones), systems for sound reinforcement and entertainment purposes, etc.

Recent legislative actions directed toward noise control have provided a legislative incentive or imperative to ensure that such factors as product noise emission or workplace noise levels are within prescribed limits. This legislative imperative is a relatively new element in the motivating factors for acoustical measurements, and has given rise to a burst of activity and attention to noise measurement tools and methodologies. Many current NBS measurement activities typify those required for the enforcement of noise control legislation, the calibration of measurement instrumentation, and the quantitative assessment of hearing loss.

3.1.1.2. Impacts on Technologies

Ultrasonic flaw detection is an excellent example of a technology which has grown rapidly in recognition of the possibility of making use of acoustical measurements to serve some desired goal, in this case, non-destructive testing. Acoustical measurements are also central to the implementation of the growing noise control technology. Within noise control technology there is somewhat less direct concern with the measurement process, *per se*. However, there is inevitably an implicit reliance upon the objective quantitative knowledge to be obtained from acoustical measurements, if the measurements are for any of the following purposes:

--- calibration of instrumentation

--- characterization of product noise emission

--- evaluation of the effects of design changes

--- characterization or monitoring of environmental noise levels

--- characterization of acoustical properties of architectural materials and systems

--- characterization of auditory acuity

--- prediction of human response to sounds from physical measurements.

The technological impact of the various measurements is far-reaching. Two examples should serve to illustrate this fact: the impact of the microphone calibration process, and the impact of the audiometric examinations required by the Occupational Safety and Health Administration.

Figure 8 presents a block diagram to illustrate the extensive technological impact of precision microphone calibration processes on our society. In figure 8, the top portion of the flow diagram indicates the basic physical measurements required to carry out the absolute pressure and absolute free field calibrations of microphones. Comparisons of these data yield the origin of the free-field correction, and provide input for the evolution and improvement of measurement standard American National Standard Method for the Calibration of Microphones, S1.10-1966 [9].

The use of the NBS pressure microphone calibration service or of the measurement standard will yield a knowledge of the microphone calibration which enables one to infer pressure data from corresponding electrical data. One then may make use of a calibrated microphone to perform laboratory and field measurements of sound. These measurements are central to...

--- characterization of noise

--- sound power measurements

--- architectural acoustics

--- audiometry

--- hearing aid calibration

--- human response to sounds

--- communication systems and broadcasting

--- sound recording and reproducing.

The range of the related technologies requiring these types of information touches upon much of our daily existence.

Section 2.4.4.5. described some of the impacts of proposed changes in the Occupational Safety and Health Administration workplace noise exposure rules, and indicated the reliance upon audiometric testing that will be used to detect damages in hearing thresholds. A four- to ten-fold increase in the number of annual audiometric measurements may take place as a consequence of these changes in the regulations.

All of the research and development in audiometry is closely allied with the needs and problems of international and national standards committees to formulate standards for equipment and criteria for measurement of hearing. These standards have been accepted by the industry (who have participated in their formulation). Many of the standards approved by societies such as the American Academy of Opthomology and Otolaryngology and the American Speech and Hearing Association have been incorporated into state and Federal Law. Thus, the equipment used in the measurement of hearing, whether during a general physical examination, in a school system, in industry for employees, in a government medical office or in the armed forces, has been calibrated to meet these standards which have been written by, reviewed by, or based on research by NBS employees.

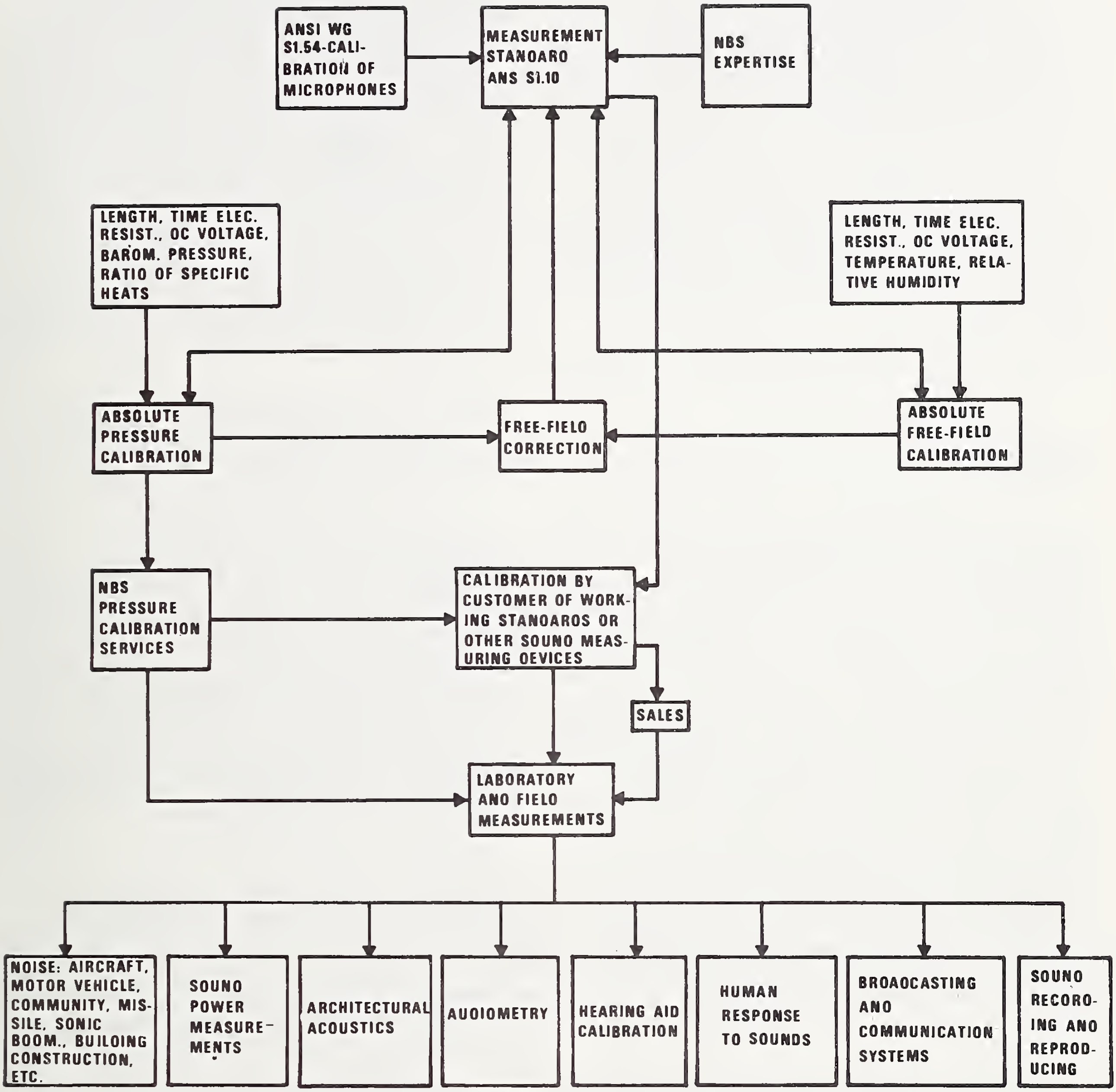


Figure 8. Technological impact of precision microphone calibration processes.

3.1.1.3. Scientific Fields Affected

During the recent past, the principal fields affected by the activities in acoustical measurements have been the related engineering disciplines, principally electrical engineering, mechanical engineering, aerospace engineering, civil engineering, and the newly established interdisciplinary field, acoustical engineering. Interactions with more basic scientific fields such as physics and mathematics have continued to be important. Substantial growth of some of the related social sciences, including the field of audiology and psychoacoustics, in response to societal concern over noise has also taken place.

3.1.1.4. Impacts on End Users

There are three broad types of impact on the end user -- social, technological, and economic.

Accurate characterization of the acoustical properties of architectural materials facilitates noise control engineering in buildings. However, it is interesting to note that while many of these materials are advertised as products specifically advised for their acoustical utility, aesthetic and mechanical construction factors as well as cost factors enter as important elements in the marketing process. The consumer often implicity assumes that "acoustical materials" have acoustical merit, without explicit evaluation of the acoustical measurement test data. It is nonetheless extremely important that the test data be obtained with the use of standardized measurement procedures, that the data be made available as product specifications, and that the consumer be trained in the interpretation of the test data so that the utility of acoustical materials can be properly assessed.

Measurements enable the development of improved noise control products through assessment of the effects of variations in the manufacturer's design engineering process. Further, through open publication of accurate test data, it becomes possible for products with demonstrable superiority to succeed in the open market, and equally for inferior products to fall into disuse and be eventually removed from availability. Provision of accurate measurement services, and publication of the data facilitate these natural scientific and economic processes.

There is little available data at present to document the total national annual expenditure for the measurement of sound absorption and insulation. This is largely a consequence of the fact that the tests are often conducted in a relatively small number of industrial laboratories, and that the industrial representatives do not release these data. Some data are available, however, on the 1973 expenditure for evaluating the sound absorption properties of acoustical materials [37]. The statistics concern tests conducted by independent laboratories. In 1973, 486 tests of sound absorption were conducted for total fees of $73,000, while a total of 122 tests of ceiling attenuations were conducted for $31,000.

An additional expenditure of $78,000 for 156 evaluations of the sound insulation of walls, floors, and other building constructions is also documented [38].

Thus expenditures of somewhat less than $200,000 are cited for independent laboratory tests. At least another $50,000 to $100,000 is spent annually to assess the impact and acoustical properties of resilient flooring materials and carpeting, and another $250,000 may be spent to conduct acoustical measurements concerned with architectural materials at the various industrial laboratories. Thus one can identify a probable total annual expenditure for acoustical measurements of this type to be somewhat more than $500,000.

Other significant impacts can be identified as consequences of the measurement of such parameters as product noise emissions or the detection of flaws in materials through non-destructive testing. But these measurements are less commonly performed at standards and testing laboratories and are dealt with elsewhere in this report.

3.1.2. Economic Impacts

3.1.2.1. Costs of Measurement

A principal source of direct economic impact of the measurement of noise emission is that related to the enforcement of regulatory actions. The measurement methodology used to implement noise control regulations must be technically, administratively, and economically feasible and reasonable. The ultimate determination of appropriate satisfaction of the "feasible and reasonable" criteria must be adapted to the probable characteristics of the chosen noise source. Unfortunately, the economic implications of the selection of appropriate measurement methodologies have not been adequately assessed. Recent Environmental Protection Agency activities, pursuant to implementation of Section 6 of the Noise Control Act of 1972, "Noise Emission Standards for Products Distributed in Commerce", will yield pertinent information. Contracts have been written with at least two consulting firms to carry out cost effectiveness studies to estimate the manufacturing costs associated with noise reduction of a number of classes of products. The nature of these studies is described more fully in Section 3.1.2.3.

The studies conducted for the Environmental Protection Agency are intended to address the issue of manufacturing costs associated with specified levels of noise reduction. Two additional types of costs are of interest in the context of this report. They are the costs associated with (1) performance of a specified measurement operation or with the performance of many similar measurement operations assessed over the nation or an industry for some specified time period, and, in contrast, (2) the costs associated with some specified amount of measurement uncertainty. Examples of these costs are given in the following material. It should be noted that these data are not as detailed as would be desirable. Further studies of these costs should be conducted, probably under the direction of professional economists.

As an example of the costs associated with specific measurement operations, the following can be cited.

Formerly, in order to ascertain compliance with the Department of Housing and Urban Development noise standards for site noise levels, an initial capital investment of the order of $8000 was required for the necessary instrumentation. The labor costs to conduct the measurement involved approximately 9 man-days to obtain the data and an additional 5 man-days for data analysis, amounting to between $2000 and $4000.

Because of the expense of these tests, NBS has, at the Department of Housing and Urban Development's request, developed special purpose instrumentation which would require an initial capital investment of from $1500 to $3000, dependent upon the configuration chosen. This instrumentation is designed to conduct the data acquisition and analysis operations automatically, and can be installed by an unskilled person. The labor costs associated with the conduct of the test should be on the order of $50, a very substantial reduction in the costs of both instrumentation and data acquisition and analysis.

Previous sections have indicated the nature of measurements conducted to determine the sound absorption and isolation properties of architectural materials, and of economic factors involved in these measurements.

Costs associated with measurement uncertainty are briefly indicated in Section 3.1.2.3.

3.1.2.2. Economic Benefits of Measurements

It is difficult to quantitatively assess the economic benefits of acoustical measurements because many of the measurements are conducted in order to quantify or reduce the noise emissions of products, and the economic value of noise emissions cannot be easily quantified. While it is generally appreciated that the absence of noise must have some economic value, it is difficult to assess this value. Since the market does not impose severe penalties on the producers of noise, more noise is ultimately emitted than is desired from society's point of view. This is a situation analogous to other pollution problems (air, water, etc.) that have arisen. The final selling prices of noisy products (or of those whose production involved significant noise pollution) is frequently lower than it should be and more of the devices are produced and used than should (ideally) be. Costs accrue to those affected by the noise produced in the use and production processes.

Other economic factors enter into the estimation of economic benefits of measurements, factors such as:

--- relief of the possible necessity of overdesign of a product to meet some specified noise emission regulation, provided the measurement uncertainty is small

--- the assurance of ability to meet some specified procurement noise emission standard, and assurance of a competitive position in the marketplace

--- the assurance that product features are realized and that proposed design changes are substantiated by quantitative data

--- provided that measurement uncertainty is small and unit-to-unit variability is small, the manufacturer of a noisy product may not be required to test 100% of production, but may rely upon sample testing, thus lowering the costs of testing.

3.1.2.3. Example of Economic Cost Benefit Analysis

Considering material obtained from a recent Environmental Protection Agency sponsored study of manufacturing costs associated with noise reduction for medium- and heavy-duty gasoline powered trucks [39], figure 9 shows the estimated manufacturing costs to produce vehicles having a given noise level. The area between the two curves on the graph represents the uncertainty in the estimates. (These curves are based upon a very limited number of points, and a much larger number of data points, in general, are required to accurately define curves of this sort.) Note that as the noise emission levels are reduced the costs rise sharply. The rate of change of this curve (slope) can be studied to obtain the incremental cost of quieting ($/dB).

3.1.3. Social and Human Impacts

Acoustical measurements are frequently conducted because of human or social interest in sound or noise. For many reasons, some of which have been previously indicated, it is difficult to assign economic value to the measurement process itself, or indeed, to factors such as the absence of noise.

The impact of these acoustical measurements upon our society can perhaps best be appreciated by realization of the possible consequences if it were not possible to perform acoustical measurements. For example,

--- it would not be possible to quantitatively assess the impact of design changes in the process of product development and the entire technology of noise control could not function effectively

--- communication system, sound reinforcement, or entertainment uses of acoustics could not be improved

--- perhaps most importantly, the noise control regulations which did evolve would have to rely upon qualitative prohibitions, such as those laws prohibiting "loud and unnecessary" noises. Reliance upon such qualitative descriptors are subject to appreciable ambiguity and enforcement can easily become inequitable.

Acoustical measurements are central to the quantitative assessment of, and protection against, noise-induced hearing loss. Hearing loss itself is a topic within acoustics which is very difficult to describe in economic terms, although there are undeniable economic aspects to the subject. For example, the publication "Hearing Level of Adults" [40] estimates that in the United States at least 1.2 million persons have a severe hearing handicap. Costs of disorders of hearing were recently put at $100 million annually [41]. This includes direct expenditures for the education of the acoustically handicapped, the training of specialists, and therapeutic measures such as hearing aids. Reduced earning power is a hidden indirect cost.

A far-reaching program to protect against noise-induced hearing loss is that of the Occupational Safety and Health Administration. The proposed final standard to protect workers from excessive workplace noise would set a limit of 90 dB for eight hours of continuous noise exposure, and would require employees to provide audiometric testing for all workers exposed to eight hour average levels exceeding 85 dB. A tradeoff ratio of 5 dB for halving or doubling of permissible exposure time is proposed; thus workers can be exposed to levels of 85 dB for up to 16 hours, or to 95 dB for four hours, 100 dB for two hours, etc. Control of workplace noise is to be accomplished primarily by engineering and administrative controls, even if these controls fail to reduce exposure to within acceptable limits. As an interim measure, the use of hearing protective devices is acceptable, but this usage is regarded as poor industrial hygiene in view of the administrative difficulties in requiring their use, overcoming worker's resistence to use, guarding against improper use and maintenance, and the hazard posed to the

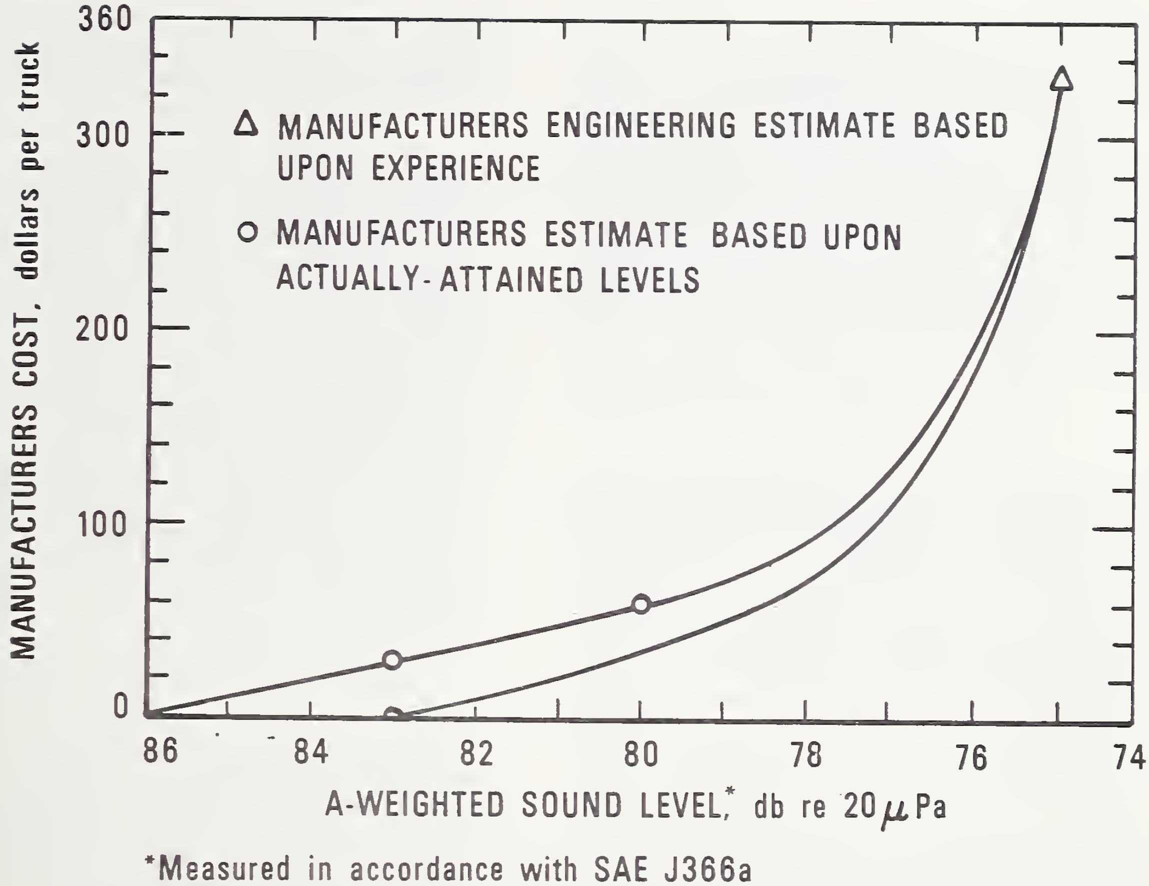


Figure 9. Estimated additional cost required to attain lower noise levels for medium and heavy duty gasoline-powered trucks. [39].

worker by being less able to detect audible signals in his work environment.

As previously noted, the Occupational Safety and Health Administration has included provisions for hearing conservation programs which will include audiometric testing for all workers exposed for eight hours to levels of 85 dB or more, and for those workers who wear personal protective equipment to reduce their noise exposure. Reliance is placed upon audiometric testing to detect changes in workers hearing thresholds, in order to permit employers to inform those workers of hearing problems before they become significant. The standard provides mandatory requirements for audiometric test rooms and for the calibration of audiometers, to ensure that the audiometric environment and techniques are well standardized and stable. [42]

As a result of the promulgation of the occupational noise exposure regulations, there are a number of commercial noise exposure meters on the market today that provide a measure of noise integrated (with appropriate weighting) over a time interval. The National Bureau of Standards, under the sponsorship of the U. S. Environmental Protection Agency, carried out an evaluation program of the devices to assess their usefulness in monitoring compliance with the regulations. A number of acoustical and electrical tests were conducted, and the results are presented in a joint NBS/EPA report. [28]

A dramatic example of the potential impact of ultrasonic non-destructive testing can be cited. In the case of the nuclear powered submarine Thresher, which sank in 1963, possibly due to failure of a silver-brazed saltwater pipe, only 145 of Thresher's several hundred silver-brazed pipes were tested with ultrasonics. Yet 14% of those tested were found to be faulty [43]. The possibility exists that the disastrous loss might have been eliminated if the ultrasonic testing program had been more extensive, and the results relied upon for elimination of probable flaws.

3.2. Status and Trends of the Acoustical Measurement System

If we mainly direct attention to those acoustical measurements which are primarily motivated by increasing social concern over noise, then a growing concern about the adequacy of noise emission and monitoring methodologies can be identified. There are numerous identifiable deficiencies in the organization, structure, and interconsistency of the relevant acoustical standards and consequently, the regulations which utilize such standards. Inconsistencies result from unnecessary duplications of effort and needless insistence upon incorporation of adaptations to appease special interests. In responding to what are regarded as emergency situations, mandatory standards are sometimes put together in patchwork fashion. Participants in the acoustical measurement system seem to be increasingly aware of the intolerable nature of this situation, and there appears to be a growing concern for increased consistency in the relevant measurement standards. For example, a report was written by NBS for the Consumer Product Safety Commission in which the problem of possible discrepancies among noise regulations established by different government agencies is discussed with suggestions for obtaining uniformity. [44] However, whether or not the relevant regulatory agencies participate fully in this movement for simplification remains to be seen.

There is likewise considerable duplication of effort in the area of noise regulation and allocation of regulatory power. As Mayo and Ware [32] have noted, "More cities are developing comprehensive noise statutes. Recent legislation in Chicago, Minneapolis and New York and proposed legislation in Boston demonstrate this. Cities are establishing noise abatement offices for enforcement purposes. Local governments are becoming more sophisticated, replacing subjective standards with quantitative standards to an increasing extent.

"As with the cities, more States are becoming concerned with noise regulation. States are setting up environmental departments with authority in the noise area or adding noise control as one of the environmental factors to which these departments should give attention. The number of noise sources being dealt with by State regulation is growing. The States are also becoming more sophisticated in their approach and are substituting quantitative standards for old subjective limits. However, in the area of aircraft noise control, no State seems willing to follow California's lead. The extreme complexity of this problem technologically, economically, legally and politically discourages State action.

"Under the Noise Control Act, however, state authority will be limited. States and cities may not prescribe standards with respect to new products covered by Federal regulations unless they are identical to those regulations. However, states and cities are free to establish and enforce controls on noise by restricting the use, operation, or movement of any product. States and municipalities are prohibited from issuing any noise emission regulations applicable to railroads or motor carriers unless the Administrator of EPA and the Secretary of Transportation determine that such standards are necessary and that they are not in conflict with Federal regulations.....

"It is a recognized fact that the existing Federal/State/Local regulatory relationships are in a situation of substantial disarray. One outcome of Federal intervention may likely be a realignment of the Federal/State/Local regulatory arrangements into a relatively symmetrical structure of laws, regulations, and enforcement practices. This could come about in time through the promulgation of Federal standards, through negotiation among various jurisdictional levels, through agreements for Federal support to states and municipalities, and by court decisions (where disputes arise) which will, hopefully, tend to bring the overall regulatory scheme into coherent and workable alignment." [32]

At the present time, NBS interaction with the Federal agencies responsible for noise abatement measures is quite active and satisfactory. However, interaction with the state and local governments is, at best, sporadic. It is planned to intensify this relationship in the future.

A current gap in the measurement system is noted when one considers the measurement of acoustical properties of architectural materials and systems. It appears likely that within the next decade building codes and procurement policies for large organizations will frequently include acoustical performance specifications. In order to satisfy these specifications, it will be essential not only to conduct many more tests, but also to devise more satisfactory field measurement test procedures. New or improved measurement methodologies are essential to evaluate noise transmission through the exterior walls of buildings and for plumbing and structure-borne sound. If these steps are not undertaken, the present deficiencies in the measurement system will continue to deteriorate.

It is particularly distressing to realize that the technology of ultrasonic flaw detection relies heavily upon empirical data based upon reference blocks which are not adequately specified. This technology is badly in need of more reliable reference artifacts, and of more precise means of system calibration.

Table 8 presents a tabular representation of some of the factors entering into discussion of forces for, and barriers to, both stability and change of the system.

Because nearly all acoustical measurements are presently based upon a metric or SI system of units, there will be negligible impact when the United States adopts the SI system of units. A possible exception to this may occur in ultrasonic non-destructive testing, since there is strong reliance upon a non-metric system of reference blocks.

An interesting scenario for the future can be constructed in consideration of the implications of the currently proposed Occupational Safety and Health Administration regulations described in Section 2.4.4.5.

For a reference data base, we should realize that in 1972, between 1.8 and 3.0 million individuals were seen for audiological services, including hearing tests. These tests were largely administered by speech pathologists, audiologists certified by the American Speech and Hearing Association, or by certified audiometric technicians. This latter category refers to individuals who can show documentary evidence of the satisfactory completion of a course of training meeting, at a minimum, the standards specified by the Intersociety Committee on Audiometric Technician Training [45] or of certification by the Council for Accreditation of Occupational Hearing Conservation Technicians.

With the passage of the Federal Occupational Safety and Health Act of 1970, noise levels in all industries throughout the country are limited. According to the Department of Labor's current Guidelines, audiometric tests must be made of all individuals working regularly or infrequently in areas in which the A-weighted sound level exceeds 90 dB. A current estimate of the number of workers so affected in manufacturing alone is approximately 2.5 million [46], without consideration of workers in other noisy industries, such as construction.

If proposed changes in the Occupational Safety and Health Administration legislation take place, the threshold level for annual audiometric testing will be lowered to 85 dB. This will significantly increase the number of workers whose hearing must be measured. There are no satisfactory data upon the number of workers involved, but two sources within the Occupational Safety and Health Administration estimated the total number at between 14 to 40% of those involved in manufacturing industries. Since the total number employed in manufacturing industry is approximately 55 million, somewhere between seven to twenty million is the approximate number of required annual audiograms. Thus this represents approximately a four-fold to ten-fold increase. If it proves that as many as twenty million annual audiograms are required nearly one in every ten citizens will be tested annually, with the concentration of measurements as high as 4 out of ten in the manufacturing industries.

In order to conduct these examinations, there will be a significant increase in the number of trained audiologists, otologists, and in the number of audiometers required. Because of the impact of forthcoming OSHA regulations, audiometer manufacturers

Table 8. Factors related to stability and change.

	Stability	Change
Forces For	The voluntary consensus standards writing community which is such a central element in the system is inherently a very conservative apparently democratic institution, which makes changes occur more slowly.	The proliferation of inconsistent measurement standards and metrics is known to be intolerable, with the result that some of these standards will have to be revised or dropped.
Barriers To	The proliferation of inconsistent measurement standards may make it difficult to implement effective noise control legislation and enforcement with the result that in the future there may be little reliance upon quantitative characterizations.	The voluntary consensus standards institutions include among their members representatives of manufacturers, trade associations, or testing laboratories who seek to delay acceptance of measurement methodologies the adoption of which might prejudice the economic well-being of that organization.

anticipate significant increases in annual sales.

The problems of providing adequate audiometric services for compliance with revised OSHA regulations have been illustrated by Dr. Allen Cudworth, Vice President and Director of Research for Liberty Mutual Insurance Company [47]. Dr. Cudworth indicated that a typical audiometric examination requires 10 to 20 minutes, so that one can hardly accomplish more than 20 tests per day per audiometer. Twenty million audiograms then will require at least 1,000,000 audiometer days annually. Because there are probably something like 100,000 work places potentially affected by the proposed regulations, if each workplace is to be supplied with its own audiometer, there will be an extraordinary demand for a large number of instruments, and each instrument will be utilized for a small fractional part of the work year. Not only does this pose unusual production and calibration demands upon the industry, but it requires that something like 100,000 trained audiometric technicians be available. A likely solution to this problem will be the use of mobile audiometric units, to best utilize the available instrumentation and trained personnel. There are indications that this will in fact be a characteristic feature of this portion of the acoustical measurement system, since the use of these facilities is currently an element of the services of an increasing number of noise control consultants.

Other possibilities for the future include:

...An emerging technology which may be limited by measurement capability is that of ultrasonic non-destructive testing. As practiced now, this technology uses a large and wide-ranging body of empirical knowledge which is based on physical phenomena and scientific principles. The closing of the gaps between the "clinical" or industrial practice and the understanding of the physical processes has been accomplished only partially -- and then largely only in defense, aerospace, or nuclear energy applications. At this time, the better engineering departments and industrial laboratories are able to establish and maintain control of their measurements within particular manufacturing process cycles and some entire plants. However, compatibility in results from measurements between plants and between companies ranges from good (at best) to entirely unacceptable. This situation appears to be one which may be amenable to solutions through the development and dissemination of evaluated measurement methodology, well-characterized physical standards, and reliable technical data.

...Because of the many possibilities for error which may occur with the operation of complex instrumentation systems, it appears likely that automated systems for the calibration of measurement instrumentation will be developed for use by the larger acoustical laboratories. In addition, automated noise monitoring systems such as that developed for the Department of Housing and Urban Development by NBS and several systems presently available on the commercial market for less complex measurements will be more widely used. Automated systems for the performance and analysis of audiometric tests will also be devised.

...Several technologies will become more measurement intensive within the foreseeable future. These include:

--- environmental noise monitoring

--- audiometric examinations

--- applications of ultrasonics, such as ultrasonic flaw detection.

4. SURVEY OF NBS SERVICES

4.1. The Past

During World War I, acoustic transducers were developed and the study of underwater sound ranging received much attention. (At the National Bureau of Standards, this work led to the establishment of the Sound Section which was formally integrated into the Institute for Basic Standards.)

In a 1966 editorial in the Journal of the Acoustical Society of America, [48] noting the dedication of the NBS Gaithersburg Laboratories, Editor-in-Chief Dean R. B. Lindsay said in part,

> "...The Sound Section, familiar to all readers of this Journal, has during its existence concerned itself with every branch of acoustics recognized in our Index Classification save music and bioacoustics. It has, in particular, done calibration, audiology, vibration measurements, long-range propagation in the atmosphere, and magnetic recording, as well as attenuation and dispersion in gases."

In 1972, the Applied Acoustics Section (formerly the Applied Acoustics and Illumination Section, Center for Building Technology, Institute for Applied Technology) was transferred into the Institute for Basic Standards. The Applied Acoustics Section has concerned itself with a number of acoustical problems, principally those dealing with the technology of noise measurement, monitoring and control. Significant contributions to the data bases on truck and portable air compressor noise as well as several new innovations in instrumentation systems for the acquisition and interpretation of environmental noise data have been accomplished. Attention has also been directed to study of the adequacy of present measurement methodologies for the determination of noise emission from several noise sources, and to assess the acoustical properties of building systems.

Research elsewhere at the National Bureau of Standards, e.g., in such diverse fields as vibration measurement, rheology, instrumentation, engineering mechanics, statistics and digital signal processing, while not directly relevant to acoustical measurements, have made significant contributions to facilitate and further the understanding of the basic physics which underpins all acoustical measurements and analytical procedures.

Table 9 summarizes the published output of NBS in this field as of December 1972. Additional publications by current staff members who were not employed at NBS at that time, or were conducting research in other fields, are numerous, but are omitted. The papers cited are those published in archival journals by present staff members. Letter reports and other minor reports are omitted.

4.2. The Present Scope of NBS Services

4.2.1. Description of NBS Services

4.2.1.1. Support of The International Measurement System

There are two principal activities by means of which NBS provides support to the international measurement system. An important activity in this context is active participation in the relevant committees of the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). Throughout the past and to the present day, NBS has had active representation on these committees. At the present time NBS staff members hold the following committee assignments.

--- Secretary of the U. S. Technical Advisory Group (E33.06) to ISO/TC43/ Subcommittee 2 (Building Acoustics)

Table 9. NBS publication output in the field of acoustics.

Books and Chapters in Book

R. D. Berendt, G. E. Winzer, and C. B. Burroughs, "A Guide to Airborne, Impact, and Structure Borne Noise Control in Multifamily Dwellings" (1968).

E. B. Magrab and D. S. Blomquist, "The Measurement of Time-Varying Phenomena" (1971).

M. Greenspan, "Transmission of Sound Waves in Gases at Very Low Pressures", in "Physical Acoustics", Vol. IIA, W. P. Mason, Ed. (1964).

R. K. Cook, Section Editor, "Acoustics", in "American Institute of Physics Handbook", 2nd ed. (1963), 3rd ed. (1972).

M. Greenspan, "Acoustic Properties of Liquids", in American Institute of Physics Handbook", 2nd ed. (1963), 3rd ed. (1972).

M. Greenspan, "Translational Dispersion in Gases", in "Dispersion and Absorption of Sound by Molecular Processes" (1963).

M. Greenspan, "A Sing-Around Velocimeter for Measuring the Speed of Sound in the Sea", in "Underwater Acoustics", V. Albers, Ed. (1963).

R. K. Cook and P. Chrzanowski, "Transmission of Airborne Noise through Walls and Floors" in Handbook of Noise Control", C. M. Harris, Ed. (1957).

M. Greenspan, Articles: "Damping"; "Forced Oscillation"; "Impedance, Mechanical"; and "Lissajous Figures" in "McGraw-Hill Encyclopedia of Science and Technology" (1960) (Also in 2nd and 3rd ed.)

Papers and Reports

Subject	Papers (No.)	Reports (No.)
Theory, including propagation and diffraction	13	2
Architectural acoustics and noise	17	22
Speech and hearing, including hearing aids, audiometry, loudness	21	87
Electroacoustics, including microphones, sound recording, instrumentation	22	10
Communication theory	6	2
Physical acoustics, including ultrasonics	24	33
Vibration	15	5
	118	161

--- Member of Working Group 6 "Noise Emitted by Machinery and Equipment" under ISO/TC43/Subcommittee 1 (Noise)

--- Member of Working Group 5 "Noise Emitted by Ships and Railways and Noise Inside Vehicles" under ISO/TC43/Subcommittee 1 (Noise)

--- Member of ad hoc group of ISO/TC43/SC1 for "Classification of Machinery and Equipment with respect to the Noise Emission."

--- Member of Working Group 2 "Free-Field Calibration of Microphones" for IEC/29/SC29

Another activity which provides support to the international measurement system is through exchange of technical publications, by attendance at international conferences, symposia, etc., and by discussions with and visits to the facilities of foreign standards laboratories. As a specific example of such support, the National Bureau of Standards hosted the meetings of IEC/TC29, its Subcommittees and Working Groups, and as well, the meetings of ISO/TC43/SC1 and its working groups in April 1976.

4.2.1.2. Participation in Standardization Organization Activities

Participation of NBS staff members in the national voluntary concensus standards organizations is documented in table 10, which shows the names and titles of the relevant committees in which NBS staff members participate. It is the concensus of the NBS staff members who belong to these committees that the committees are currently quite active and productive, and that it is a worthwhile endeavor for NBS to be involved in.

4.2.1.3. Development of Measurement Methods

The result of NBS research activities is frequently the development of measurement methodologies. These outputs have traditionally been an area in which NBS has provided leadership. Typically, the first output of NBS research or measurement expertise is the conception of a measurement methodology, a data base is then obtained with the implementation of the measurement methodology, and ultimately, the improved, tested, and proven measurement methodology is accepted within the standardization community. Section 4.2.1.4. describes some current NBS activities related to measurement methodology and the provision of data bases; the following sections describe some prior activities resulting in accepted measurement methods.

Measurement of sound pressure: In the late 1930's, an investigation into the basic physics of how a fluctuating sound pressure, acting on a microphone, is converted by the latter into fluctuating electrical voltages and currents was carried on. The resulting technical scheme is now known as the reciprocity method for calibration of microphones. The basic description of the method was published in appropriate scientific and engineering journals.

Shortly, it became apparent that several methods for calibration of microphones were being used, including the reciprocity method. The systematic differences in the results of the several methods forced a decision to select a single standard method for such calibrations that would furnish the most accurate scheme for arriving at absolute measurement of audible sound pressure. Agreement on a single method would lead to compatibility in data obtained in various laboratories with different instruments. A technical committee of the American National Standards Institute was appointed. This committee was made up of acoustical experts and included NBS representation. In due course, the reciprocity method was agreed upon and an American Standard Method for Calibration of Microphones[9] was approved and is widely used.

Measurement of sound power: The absolute measurement of the total amount of acoustical power radiated by sound sources such as houshold appliances, gasoline engines, etc., is only partially achieved in most cases. The total radiated power is important because it governs, to a large extent, how much annoyance is created by the noise. Such acoustical powers are relatively small, frequently less than 1 watt, and therefore require special facilities for measurement.

In the late 1940's, NBS modified its reverberation chamber facilities for measurement of such powers. This facility had been set up in the 1920's for measuring the absorption coefficients of the newly-invented acoustical materials used to control sound and noise in offices, shops, public buildings, etc. An investigation

Table 10. Participation in national standards organization activities.

Organization	Committee, Sub-Committee, or Working Group Title
Audio Engineering Society	-- "Stethoscopes Committee" (member)
American National Standards Institute	-- Acoustics Technical Advisory Board (2 members) -- Committee S1: Acoustics -- 45 Sound Level Meters and Their Calibration (member) -- 54 Standard Microphones and Their Calibration (member) -- SC57 Attenuation of Sound in Air (member) -- 61 Evaluation of Absorptive Wedges and Anechoic Rooms (member) -- Committee S3: Bioacoustics -- 35 Audiometers (member) -- 37 Coupler Calibration of Earphones (member) -- 43 Method of Calibration of Bone Vibrator (members) -- 43 Artificial Head-Bond (member) -- 48 Hearing Aids (member) -- 51 Auditory Magnitudes (member) -- Committee S4: Sound Recording (member)
Acoustical Society of America	-- Acoustical Society of America Committee on Standards (2 members) -- Working Group 3: Motor Vehicle Engine and Tire Noise (member)
American Society for Testing and Materials	-- Committee E18: Sensory Evaluation of Materials and Products (member) Subcommittee 04: Psychophysical Measurement of Environmental Pollution (member) -- Committee E-33: Environmental Acoustics (3 members) -- Subcommittee .01 "Sound Absorptions" (3 members) -- Subcommittee .03 "Sound Transmissions" (3 members) -- Subcommittee .06 "International Standards" (member) -- Subcommittee .08 "Mechanical and Electrical System Noise" (member)
Institute of Electrical and Electronic Engineers	-- Standards Committee 6-AE "Earphone Measurements" (member)
Society of Automotive Engineers	-- Committee A21 Aircraft Engine Noise -- Subcommittee: "Subjective Evaluation of Flyover Noise" (member) -- Committee "Vehicle Sound Level" -- Subcommittee "Instrumentation" -- Ad hoc Group on "Vehicle Noise Test Environment" (member) -- Monitoring Panel for Audible Warning Systems (member)

into the use of such chambers for sound power measurement was launched in the early 1950's. The electroacoustical facilities were modified so as to incorporate the absolute sound pressure measurement capability, which came from the reciprocity method (see Section 4.2.1.4.1.). The results of the first researches led (a) to a scheme, using the measurement of correlation coefficients for sound fields in reverberation chambers, for arriving at an estimate of the state of diffusion in the chamber, and (b) to an estimate of the errors in measurement of sound power arising from the arbitrary method used to sample the sound fields in the chamber.

The technical problems connected with achieving a diffuse field, and with sampling the sound pressure of the diffuse field, were substantial enough to require continuing research into the acoustics of reverberation chambers to the present day.

The most recently accepted standard for the measurement of sound power is American National Standard Methods for the Determination of Sound Power Levels of Small Sources in Reverberation Rooms, S1.21-1972 [49]. This standard, as now embodied, represents a major advance in the state-of-the-art of reverberation room measurement of sound power. It incorporates the best currently available interpretation of measurement technology which is the subject of ongoing research. However, in order to identify additional analytical and experimental information needed for further refinement of this standard, NBS sponsored, under contract, a critical review of this standard which was published in May 1974, as NBS Technical Note 841 [50]. The report was made available as a relevant commentary on the state-of-the-art and in the interests of an open exchange of information.

Miscellaneous acoustical measurement methods: The widely used American Society for Testing and Materials method of test for airborne sound transmission [16] loss is a direct outgrowth of NBS research several years ago [34,35,36].

The Consumer Product Safety Commission (formerly the Bureau of Product Safety of the Food and Drug Administration, HEW) issued regulations on the allowable noise levels from toy cap guns. Manufacturers and their consultants were found to be using inappropriate measuring techniques, leading to very large (40 decibel) errors in the measured peak sound pressure levels. NBS rectified this situation by carrying out laboratory measurements and then, based on these measurements, prepared for Consumer Product Safety Commission performance specifications for the measurement systems [51], which led to suggested measurement methodologies for measuring the noise of paper caps [52] and toy guns [53].

Using an acoustic coupler which was developed at NBS more than thirty years ago, and a standardized procedure, NBS offers a service for the calibration of audiometric earphones. Such a calibration procedure is critical to the calibration of all hearing-test devices.

NBS has had a continuing program with the Veterans Administration (VA) to determine numerous electrical and acoustical characteristics of hearing aids. Though a discussion of the properties of these devices, and description of the nature of these measurements, is beyond the scope of this report, the complete results of these tests are published annually in a document published by the VA and which is obtainable from the U. S. Government Printing Office. Current work is now devoted to developing test methods to determine the acoustic response of two new types of hearing aids, the directional hearing aid and the open-ear mold or high-pass hearing aid.

NBS is presently in the midst of a major effort to determine the electrical and acoustical properties of sound level meters in a variety of physical environments and to devise a standard calibration procedure to verify that sound level meters meet the relevant (usually ANS S1.4-1971) specifications. It is anticipated that a calibration/evaluation service will be offered to government and industry within the near future.

4.2.1.4. Provisions of Reference Data

The principal means by which NBS provides reference acoustical data is through the technical reports on its research studies and by participation in national and international acoustical measurement round robins. Several significant accomplishments can be cited as examples of these services.

1. Truck tire noise: At medium to high speeds, the noise from tires predominates provided the truck has a reasonably good exhaust muffler and is in a good state of repair. Users and manufacturers of truck

tires, state lawmakers and enforcement agencies, and urban planners have been hampered in their noise abatement efforts by the lack in the public domain of an information base of tire noise data. An NBS research program, which served as the basis for the test procedure adopted by the Society of Automotive Engineers [54], is one facet -- along with the diesel truck demonstration project, truck muffler optimization program, and the training/equipping project -- of the Department of Transportation program in surface transportation noise aimed at nationwide highway vehicle noise enforcement.

2. Interior/exterior noise of over-the-road trucks [55]: On November 7, 1970, the Bureau of Motor Carrier Safety (BMCS), issued an Advanced Notice of Proposed Rulemaking Concerning Vehicle Interior Noise Levels. A total of forty responses to the docket was received; however, they provided little real data on the level and effect of in-cab noise on drivers hearing and less yet comparing improvements in interior noise levels to decrease in exterior noise levels. Therefore, in order to develop a factual information base regarding the noise levels of typical over-the-road trucks, NBS conducted a data base measurement program, the output of which includes:

a. Initial data which formed the basis for the BMCS regulations on vehicle interior noise levels.

b. The idle-max-idle stationary test procedure developed during this program has been utilized by the Environmental Protection Agency as one of the test procedures in their Interstate Motor Carrier Noise Regulations.

c. The experience obtained during the conduct of this program allowed NBS to develop an appropriate measurement methodology which can be used by the Environmental Protection Agency in their Noise Emission Regulations for New Medium and Heavy Duty Trucks [56].

3. Railroads: NBS evaluated various measurement methodologies and data processing algorithms as to their appropriateness in characterizing the noise generated by rail line and yard operations, including the noise of retarders [57]. These data, in conjunction with data from other sources, provide the technical basis for the Environmental Protection Agency Interstate Rail Carrier Noise Emission Regulations. The study was prompted by lack of data on the noise levels associated with railroad operations, which necessitated the establishment of a data base prior to Federal rule making in this area.

4. Noise of portable air compressors: The Environmental Protection Agency has identified portable air compressors as a major source of noise pollution. As part of a study of procedures for the equitable determination of noise output, the sound power levels associated with seventeen different portable air compressors were determined in an extensive field measurement program. The resultant data, together with data from several other sources provides a technical basis for evaluation of measurement procedures for stationary noise sources. [58]

4.2.1.5. Provision of Reference Materials

Because of the fact that the use of reference materials is relatively unusual in acoustical measurements, the role of NBS in provision of these materials is modest.

A significant exception, however, is in the technology of ultrasonic flaw detection. In this technology, since reliance is often placed upon reference blocks for system calibration, NBS has recently evolved a program directed toward the study of the adequacy of ultrasonic reference artifacts. This research will utilize the current American Society for Testing and Materials standards to determine the size of already well-characterized flaws, initially starting with fatigue cracks in standard fracture specimens. The ultimate goal of this research is to devise, improve and disseminate the measurement techniques, standards, and test methods for acoustic-based nondestructive testing; and to facilitate, establish and maintain comparability between measuring systems to assure compatability of data resulting from inspections of the same product at different locations. As an element in this program it is likely that the present reference block system will either be more tightly characterized, or replaced with a more satisfactory system.

4.2.1.6. Support of Science, Education and The Dissemination of Knowledge

There are several direct interactions which NBS acoustics activities have had, and continue to have with the educational system. These affect all levels of education, and include:

--- provision of training as laboratory aides for high-school science students

--- provision of research experience for high school science teacher programs leading to the M. Ed. degree

--- presentation of invited lectures at colleges and universities

--- support of research through a grant to a university on the subject of reverberation room acoustics

--- support of the research of National Research Council post-doctoral research associates.

These interactions serve to disseminate knowledge about acoustics and at the same time infuse new ideas and fresh approaches into the research programs.

An additional service provided to make possible the dissemination of knowledge is through technical publications. As indicated in Section 4.1., NBS researchers have numerous publications in acoustics. At the present time, NBS researchers serve not only as authors and reviewers, but a staff member presently serves as Associate Editor for Noise for the Journal of the Acoustical Society of America, and on the editorial board of the Journal of Noise Control Engineering.

4.2.1.7. Existing Measurement Capabilities

The acoustical measurement capabilities presently existant at NBS include but are not limited to the following principal types of acoustical measurements:

--- precision microphone calibration, (reciprocity method)

--- measurement of sound pressure level

--- in a free field (anechoic) environment

--- in a semi-anechoic (free-field over reflecting plane) environment (limited to field measurements)

--- measurement of sound power emissions

--- inferred from... anechoic
... semi-anechoic (field)
... reverberation room data

--- measurement of environmental noise

--- through the use of instrumented and microcomputer data processing facilities

--- through the use of special purpose noise monitoring systems

--- measurement of the sound attenuation properties of ear protectors

--- measurement of the acoustic pressures produced by audiometric earphones

--- measurement of acoustical absorption properties

--- using the reverberation room method

--- using the impedance tube method

4.2.1.8. Role in the Dissemination and Enforcement Network

At the present time, NBS provides a reciprocity calibration service for precision condenser microphones, provided that they are made to be used with the standard calibrating couplers described in American National Standard S1.10-1960 [9]. Table 11 indicates that the users of this service include not only manufacturers of acoustical measurement equipment, but also a wider range of participants in the infrastructure. Many of the companies send microphones to NBS for calibration once a year.

Present plans for the NBS program call for the extension of calibration services possibly to include determination of such factors as compliance with performance specifications ("type testing") of sound level meters or integrating sound level meters.

Table 11. Users of microphones submitted to NBS for calibration.

Type of Industry	Examples
Manufacturers of Sound Measurement Equipment	General Radio Co. B & K Instruments, Inc. Hewlett Packard Co.
Aerospace Industry	Boeing McDonnell Douglas Lockheed Rockwell International Pratt & Whitney General Dynamics
Manufacturers of Audio Equipment	RCA Laboratories CBS Laboratories Electro-Voice, Inc. Dictaphone Corp.
Department of Defense	U. S. Naval Weapons Eng. Support Activity Newark Air Force Station Wright-Patterson AFB Redstone Arsenal
Other Government Agencies	NASA: Marshall, Goddard, Kennedy, Langley, Houston, White Sands HEW Dept. Labor Dept. Transportation Dept. Agriculture Dept.
Automobile Manufacturers	General Motors Corp. Ford Motor Co.
Equipment Manufacturers	General Electric Co. Westinghouse Corp. Rohr Corp. Bendix Corporation
Acoustical Consultants	Wyle Laboratories Bolt Beranek & Newman Western Electro-Acoustic Labs Sandia Corp.
Universities	Pennsylvania State University
Manufacturers of Audiometric Equipment	Roanwell Corp. Instrument Systems Corp.

With the increased use of audiometers as diagnostic instruments which is projected for the near future, it would be desirable to develop a measurement assurance program. This program should include all the laboratories presently calibrating audiometers as well as those to be established in the near future. Analysis of the precision and accuracy of these calibrations should be very significant in indicating improvements to the system. NBS participation ideally should involve participation with other agencies such as the Occupational Safety and Health Administration, which is now in the process of accrediting laboratories. Factors such as a round robin to deal with the subject of earphone calibration, requirement of the use of an insertion technique, the effects of operator testing, skill or technique, and an educational program would be involved.

Relationship to lower echeleon calibration and testing laboratories: This subject is discussed in some detail in Sections 2.4.3.1. through 2.4.3.5. The principal NBS interaction with these laboratories is through the common professional affiliations of the NBS staff members and the laboratory staff members in the relevant professional societies and in service on the voluntary consensus standards groups. There is not at present, and has not been, any extensive program of review of the facilities and capabilities of these laboratories. However, a survey of the capabilities of some of these laboratories on a limited number of acoustical measurement-related topics will soon be initiated with the cooperation of the Institute for Noise Control Engineering.

Relationships to regulatory agencies: NBS provides technical support and assistance to regulatory agencies with emphasis on:

--- developing improved measurement procedures,

--- establishing and/or validating data bases,

--- evaluating performance of commercially available acoustic measurement instrumentation,

--- developing new instrumentation.

In some areas, NBS support services are authorized or mandated by specific legislation, such as the Noise Control Act of 1972 or the Consumer Product Safety Act. Through participation in interagency research panels and interaction with regulatory agency personnel at the planning and decision-making level, NBS assists regulatory agencies in defining their future research programs by identifying areas where the promulgation of regulations or the ability of industry are hindered by a lack of accurate measurement procedures or data.

The principal regulatory agencies with which NBS has active interrelationships are those described in Section 2.4.4.1.3. and Appendix C, and include the Department of Transportation, Consumer Product Safety Commision, Department of Housing and Urban Development, and the Environmental Protection Agency.

4.2.1.9. NBS Input/Output for National Measurement System/NBS Interaction

Figure 10 illustrates the nature of the input/output process characteristic of the National Measurement System/NBS interaction. It is seen that the elements in this interactive process can be categorized as follows:

... Standards organizations
... Industrial
... Federal and State governments
... Professional activities
... Foreign laboratories

Each of these elements has a dual role -- as a source of information or material to NBS participants, and as a recipient of NBS data or NBS measurement expertise. It is instructive to briefly consider the elements in some detail.

Estimates of representative fractional total manpower concerned with each form of identified output are shown in figure 10.

The relevant standards organizations with which NBS acoustics staff members have active involvement are listed in tables 10 and 12. NBS staff members serve in various capacities in these organizations, and frequently serve as chairmen of committees, sub-committees, or working groups for the development of standard test methods.

Numerous interactions with industrial groups can be cited. While it is inappropriate to cite individual manufacturers or individual colleagues, the industries they represent complement those identified as members of the trade

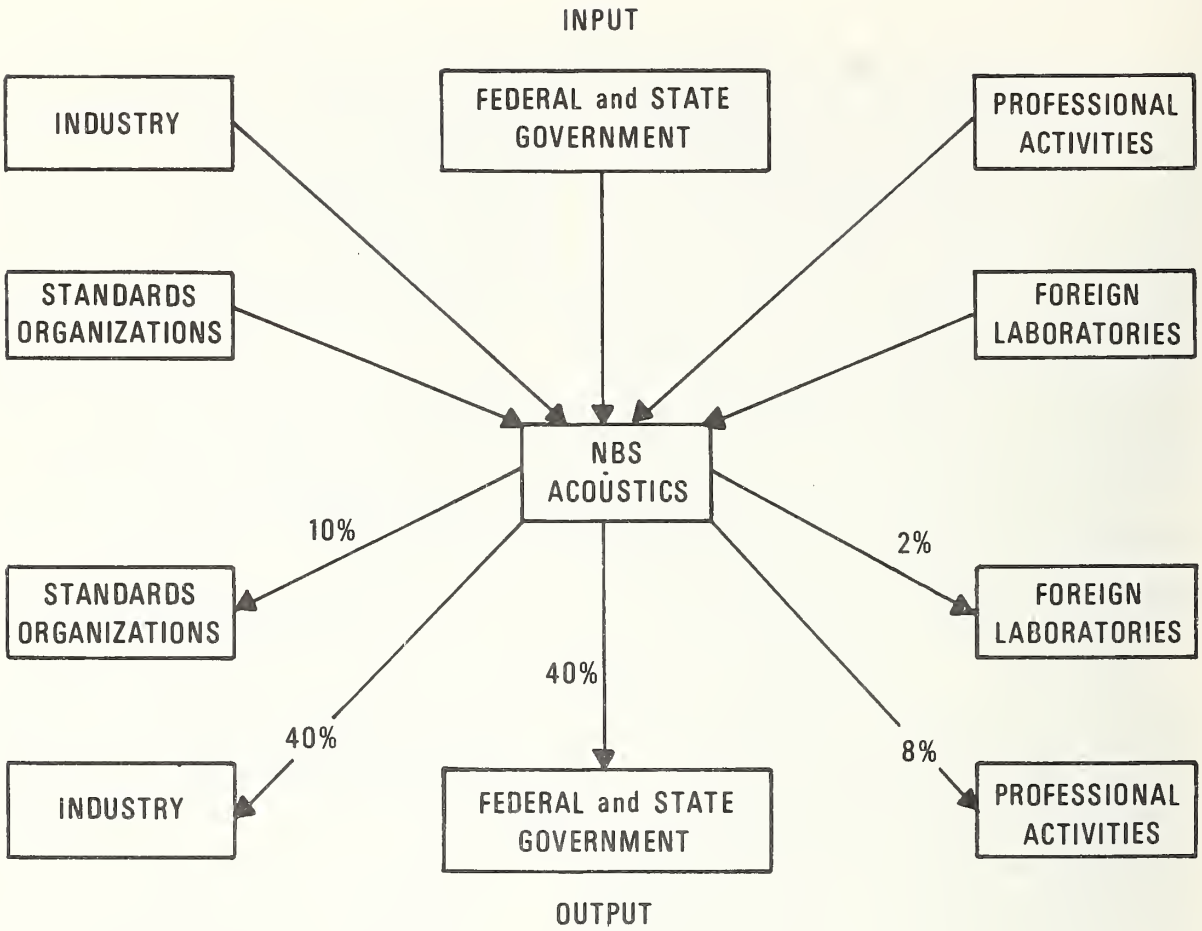


Figure 10. NBS input-output chart showing the interaction between NBS and elements of the acoustical measurement infrastructure.

associations explicitly cited in table 12. It should be noted that these groups include producers of a wide variety of noise emitting products. Recently, in establishing a measurement methodology for noise source characterization, valuable input was provided by meeting with these groups, to cite but one example.

Interactions with elements of Federal and state governments are numerous, and these are listed in table 12. Details on the nature of the interactive processes are indicated in other sections of this report.

Additional input to the NBS work in acoustics also comes from other groups within NBS. In particular, interactions with the Sensory Environment Section, Center for Building Technology, Institute for Applied Technology, are active and extensive.

Professional activities provide another valuable interaction. These professional activities consist of participation in the meetings of relevant professional and scientific societies, special symposia, preparation and review of papers published in technical journals, and meetings with faculty and staff members of various universities. Specific elements of these professional activities are listed in table 12.

Activities of foreign standards and research laboratories are important sources of input to the National Measurement System. In the context of interaction with NBS work in acoustics, the specific foreign laboratories listed in table 12 are cited.

It is, of course, important to determine the probable structure of the total input-output interactive process for the

Table 12. Participants in the National Measurement System/NBS interaction.

Standards Organizations
- American National Standards Institute (ANSI)
- American Society for Testing and Materials (ASTM)
- Society of Automotive Engineers (SAE)
- International Organization for Standardization (ISO)

Industry
- Trade Associations
  - Acoustical and Insulating Materials Association (AIMA)
  - Air Conditioning and Refrigeration Institute (ARI)
  - American Road Builders Association (ARBA)
  - American Short Line Railroad Association (ASLRA)
  - American Trucking Associations (ATA)
  - Association of American Railroads (AAR)
  - Association of Home Appliance Manufacturers (AHAM)
  - Construction Industry Manufacturers Association (CIMA)
  - Engine Manufacturers Association (EMA)
  - International Snowmobile Industry Association (ISIA)
  - Motor Vehicle Manufacturer's Association (NVMA)
  - National Electrical Manufacturer's Association (NEMA)

- Individual Manufacturers
- Colleagues in Industry

Federal and State Governments

- Federal Government
  - Consumer Product Safety Commission (CPSC)
  - Department of Agriculture (DOA)
  - Department of Defense [Air Force, Army, and Navy] (DOD)
  - Department of Health, Education and Welfare (HEW)
  - Department of Housing and Urban Development (HUD)
  - Department of Interior (DOI)
  - Department of Labor (DOL)
  - Department of Transportation (DOT)
  - Environmental Protection Agency (EPA
  - General Services Administration (GSA)
  - National Aeronautics and Space Administration (NASA)

- State Governments
  - California
  - Illinois
  - Maryland
  - New York

- NBS
  - Sensory Environment Section, Center for Building Technology, IAT (463.03)

Professional Societies
- Acoustical Society of America (ASA)
- Audio Engineering Society (AES)
- Institute of Electrical and Electronic Engineers (IEEE)
- Institute of Noise Control Engineering (INCE)

Technical Journals
- IEEE Transactions on Audio and Electroacoustics
- IEEE Transactions on Ultrasonics
- Journal of the Acoustical Society of America
- Journal of the Audio Engineering Society
- Journal of Noise Control Engineering
- Journal of Applied Acoustics
- Journal of Sound and Vibration

Universities
- Catholic University
- Massachusetts Institute of Technology
- North Carolina State University
- Pennsylvania State University
- Purdue University
- University of Houston
- University of Pittsburgh
- University of Texas (Austin)
- University of Wisconsin (Madison)

Foreign Laboratories
- Building Research Establishment (BRE) [England]
- Centre Scientifique et Technique du Batiment (CSTB) [France]
- Institute of Sound and Vibration Research (ISVR) [England]
- National Physical Laboratory (NPL) [England]
- National Research Council (NRC) [Canada]
- Physicalisch-Technische Bundesanstalt (PTB) [W. Germany]
- Technical University of Denmark (DTH) [Denmark]

entire National Measurement System infrastructure concerned with acoustics. The essence of this process is given in Section 2.5.

4.2.2. Users of NBS Services

Indications of the nature and composition of the primary users of NBS services can be obtained by study of previously presented material. In particular, the NBS Input/Output Chart categorizes the output into the following categories:

--- Standards Organizations
--- Industry
--- Federal and State Government
--- Professional Activities
--- Foreign Laboratories

The standards organizations rely upon the acoustical measurement expertise of NBS personnel and upon the participation of NBS laboratory activities in their measurement round robin programs, and, perhaps most significantly, upon the NBS basic research efforts directed toward the relevant physical phenomena.

Industry makes use of NBS acoustical measurement expertise in the development of measurement methodologies and through the use of NBS measurement services. Table 12 indicates the range of industrial trade organizations which have met with NBS personnel within the recent past, and table 11 (Section 4.2.1.9.) illustrates the nature of the users of the NBS precision microphone calibration services.

The nature of the NBS relationship with Federal regulatory agencies is described in Section 4.2.1.8. At the present time, there have been several inquiries from representatives of state governments for assistance with regard to acoustical measurements. These inquiries have included discussion of such general topics as laboratory accreditation, round-robin inter-laboratory checks, and the evaluation of the performance of measurement instrumentation. Specifically the discussions have indicated that their major problems are with sound level meters and graphic level recorders. These problems are:

... there is no place where they can have instruments tested by an independent agency to ascertain their conformance with applicable standards (e.g., American National Standard S1.4-1971 [11]);

... American National Standard S1.4 does not adequately specify the capability of sound level meters to handle high crest factor (peak to rms value) signals;

... the transient response of graphic level recorders does not conform to specifications for sound level meters, so data obtained on different instruments are not comparable.

Professional activities, other than participation in the standards committees and in the dissemination of knowledge, include the publication of research findings and the scheduling of conferences and meetings directed to the subject of acoustical measurements. As an example of such activities, NBS co-chaired the 1974 Arden House Workshop on Noise Control Engineering with the Institute of Noise Control Engineering. This conference specifically directed attention to the subject of accuracy and precision in acoustical measurements.

Because of NBS activity in fundamental acoustical measurements such as precision microphone calibration and in audiometric measurements, the indirect users or beneficiaries of NBS activities include nearly everyone who makes use of acoustical measurement instrumentation or benefits from the implementation of noise control or hearing conservation measures.

Two types of "non-clientele" who would seem to have reason to be clientele can be identified. These include some Federal agencies with which NBS has only a weak inter-relationship (such as Occupational Safety and Health Administration) and some manufacturers of acoustical materials used for noise control purposes. The relationships with the Occupational Safety and Health Administration are weak principally because the Office of Research and Standards Development of the National Institute for Occupational Safety and Health was mandated to have primary responsibility for development of the recommended Occupational Safety and Health Administration standard for exposure to noise, and therefore, employ their own scientific staff to carry out this mandate. Manufacturers of acoustical materials rely principally upon independant testing laboratories for their acoustical measurements, and are often less critically concerned with the measurement process *per se* than in the acoustical, mechanical, aesthetic, and economic properties of their products. It may be that the apparent lack of concern with the possible inadequacies of the measurement process is because the acoustical properties are often, in practice, secondary to aesthetic, mechanical, or economic factors.

4.2.3. Alternate Sources

Some calibration services comparable to those presently provided by NBS can be obtained from acoustical consultants or from independent testing laboratories. In some cases, these laboratories also provide measurement services no longer rendered by NBS, but which were at one time provided by NBS. More extensive discussions of this factor are presented in Section 4.3.3. The NBS relationship with the personnel of these alternate suppliers is principally through common professional society activities and in service in the voluntary consensus standards groups.

An identifiable user need not at present being met is the provision of calibration services for sound level meters and noise exposure monitors. There is increasing interest in the provision of such a service and present NBS plans call for expansion of the NBS program to provide such a calibration service. There are, however, indications that another Federal agency may intend to provide such a service in the relatively near future. Because these measurements are extremely complex and require appreciable expertise in acoustical measurements, such as is presently available at NBS, it will remain to be seen whether other Federal agencies will be able to acquire the essential facilities and experienced personnel to provide adequate services.

4.2.4. Funding Sources for NBS Services

There are three principal sources of funding for NBS acoustical measurements work. These sources are:

--- other Federal agency monies
--- test and calibration fees
--- scientific and technical research service funds

The principal sources of other agency monies are agencies such as

--- Department of Transportation
--- Department of Housing and Urban Development
--- Consumer Product Safety Commission
--- Environmental Protection Agency
--- Postal Service.

In general the other agency monies are obtained either as agreed upon in the terms of interagency agreements, as reimbursable projects, or as contracts. The agreements or contractual terms typically require written reports to the sponsoring agency; permit NBS to purchase essential instrumentation and (frequently) to retain this instrumentation upon completion of the contract; and encourage open publication of the results of the measurements or provision of the measurement service in the literature.

There are certain constraints connected with the acceptance of other agency orders and monies. These are intended to define such factors as whether or not traceability of the measurements to national standards may be important, whether the private sector cannot or will not develop appropriate test methods, whether contracts placed outside the Federal government would result in an unavoidable conflict of interest, etc.

Test and calibration fees are paid according to established fee schedules, and result in the provision of calibration data reports to the client.

Scientific and technical research service funds are those monies appropriated by Congress to NBS to support ongoing NBS programs.

4.2.5. Mechanisms for Supplying Services

The following serve as the mechanisms by which NBS supplies its services:

--- performance of calibration measurements

--- publications, including:

    --- articles in technical journals and magazines
    --- NBS reports

--- talks to various groups, including:

    --- professional societies
    --- trade associations
    --- university sponsored seminars
    --- representatives of state and local governments

--- meetings with:

--- other Federal agencies
--- trade associations
--- standards associations
--- representatives of foreign laboratories.

4.3. Impact of NBS Services

4.3.1. Economic Impact of Major User Classes

As indicated in earlier sections of this report, the major users of acoustical measurements include the manufacturers of noisy (or noise-control related) products and regulatory agencies. The extent and nature of use by all of the participants in the measurement infrastructure is not well understood at present, and the economic impact of the major user classes is correspondingly not well understood. Detailed study by trained economists is in order. The information presently available is fragmented, inadequately detailed, and to some extent irrelevant. Some of the varied elements in this situation include the following typical considerations, indicating the range of impacts to be observed.

--- A recent economic study carried out for the Occupational Safety and Health Administration [59] estimated that it would cost American industry $13 billion dollars to achieve compliance, insofar as technology permits, with present Occupational Safety and Health Administration regulations permitting workers an 8-hour exposure at 90 decibels. The same study indicated that it could cost an additional $8 billion to achieve compliance with an 85-decibel regulation. Thus one can estimate that the cost of reducing industrial noise in the United States by only one decibel could be on the order of $1.5 billion dollars. If only a fraction of the measurements made were in error on the high side, industry could spend vast amounts of money on needless noise control. On the other hand, measurements which are erroneously low can result in an increased number of workers suffering a hearing handicap. Furthermore, such measurement errors can lead to costly and time-consuming arguments between regulatory agencies and industry.

--- A recent article [60] indicated that there are 23 manufacturers of audiometers, 18 of which are in the United States. A survey of the five major manufacturers indicated that, in 1972, sales of audiometers in this country totalled between $4.2 and 7.2 million.

--- A study conducted in 1969 [61] documented $15 million spent on ultrasonic equipment in 1969, and projected an annual growth in this field of 15%, with a 1980 market volume of $70 million. A survey of various manufacturers estimated the 1973 total sales in ultrasonic equipment of $25 -30 million. Of this, approximately $5 million was for transducers (which, at a unit cost of $200 implies 200,000 transducers sold annually), and approximately $15 million was for ultrasonic flaw detectors (which at approximately $5000 each implies 3000 instruments sold). It is estimated that, for the international market, these figures would be doubled.

In summary, the economic impact of major users in the acoustic measurement system is poorly understood, but, nevertheless, is an important subject. The authors were uncomfortable with the economic information presented, but these were considered to be the best examples available. Obviously, a need exists to obtain more concrete and definitive economic information on this topic. To help remedy this situation, NBS has awarded a contract to a major acoustical consulting firm to prepare a definitive study on the economic impact of acoustical measurements.

4.3.2. Technological Impact of Services

The major technologies presently supported by NBS acoustical measurement services are those concerned with the implementation of noise control legislation and engineering, with hearing conservation programs, and with the relevant basic physical phenomena. These technologies and their concern with acoustical measurements are described in Sections 2.1., 2.2.2., and 3.1.1. NBS support is indicated in Section 4.2.1.

4.3.3. Pay-off From Changes in NBS Services

The NBS acoustical measurements facilities at the previous site in

Washington, D. C. included the facilities required to perform airborne sound transmission loss measurements for panels or test partitions, as described briefly in Section 2.2.2.1. These facilities included two adjacent reverberation rooms, separated by the test panel assembly. In addition, facilities existed for the measurement of impact-noise properties of floor-ceiling assemblies. For some time, the use of these facilities was made available for the measurement of transmission loss, through provision of a service at an agreed upon standardized fee. Two changes came about, to the effect that this service is not presently provided by NBS.

At the time that NBS had initiated the measurement service, alternate sources did not possess the necessary facilities, and the measurement methods had not become well accepted within the standards community. As time went on, the procedures to determine airborne sound transmission became relatively well established, and certain independent testing laboratories acquired the necessary facilities to perform these tests. At the same time, NBS facilities became somewhat obsolete. Thus, because of this factor and because other sources of the airborne sound transmission measurement service were readily available, NBS discontinued the provision of the service.

The second change brought about was the decision, at the time of construction of the NBS Gaithersburg facilities, not to include facilities for the measurement of transmission loss or for impact noise measurement. At that time, it was believed that there were enough commercial laboratories equipped to provide these measurement services that the NBS acoustics program did not require them also. The initial consequence of this decision was that it was practically impossible to conduct the relevant measurements at NBS. As it has developed, this decision has had an adverse effect, both upon the growth of NBS expertise, and upon NBS relationships with the standards community. Without the opportunity to conduct measurements of the acoustic transmission properties of building structures, the direction of NBS acoustical research has had to consciously omit the important subjects of airborne and structure-borne sound transmission properties of building structures, and NBS outputs on this topic to the standards and measurement community have been weakened. As a further consequence, neglect of the interaction of sound and structural vibration has occurred. This is an unfortunate characteristic consequence of a conscious decision to omit provision of essential measurement tools.

In order to remedy this deficiency, it will be necessary either to construct these facilities, or to make arrangements for the use of the required facilities at some other laboratory. In the absence of the required facilities, satisfactory program growth and relevance to some of the important measurement needs of the nation cannot take place, and NBS cannot develop required improved measurement procedures, provide independent test data, or participate meaningfully in the promotion of uniform measurement methods among the members of the measurement infrastructure.

At the time of these decisions, however, it was realized that an important property of acoustic fields which could not, and to this date still cannot be quantitatively characterized was that of the diffusiveness of reverberant acoustic fields. An overt reprogramming effort of available manpower to this important field took place. Despite these actions, however, no satisfactory quantitative metric for the diffusiveness of reverberant acoustic fields has been developed. Present efforts continue to be directed toward this topic, concentrating upon the application of digital signal processing and spatial sampling concepts. Several innovative concepts have evolved [62].

4.4. Evaluation of NBS Program

It is useful to note several perceived strengths and deficiencies of the NBS role in the National Acoustics Measurement System. One strength is the provision of calibration services for precision condenser microphones. The degree of accuracy and precision which characterizes these measurements is higher than that found in nearly all other acoustical measurement processes, and these measurements are utilized in the calibration of many additional instrumentation systems.

NBS acoustics staff members have played an active role in developing measurement methodologies for use by regulatory agencies, and in technical documentary standards. In the course of this work, close interactions with standardization organizations and professional societies have developed ensuring that the National

Measurement System/NBS interaction is broad in scope.

A further identifiable strength of current NBS acoustics activities consists of the evolution of sophisticated special purpose noise monitoring instrumentation systems, and the provision of test and evaluation services (as desired) for related commercially available instrumentation. These activities have provided valuable guidance and established the feasibility of constructing highly accurate, sophisticated, and reliable noise measurement instruments.

Several important deficiencies in the NBS role in the system can also be identified. Perhaps most immediately notable is the absence of test facilities required for certain important measurement processes. Specifically, the absence of a semi-anechoic test environment results in severely limited attention to measurement procedures for this condition.

Further limitations on the scope of present activities and participation in the National Measurement System infrastructure are imposed by the absence of transmission loss and structure-borne noise test facilities. As NBS knowledge of reverberation room acoustics increased, it became apparent that further research on the subjects of transmission loss and structure-borne noise were necessary. Yet, without the necessary facilities it is not possible to conduct this research. Additional limitations are imposed by the absence of state-of-the-art instrumentation, such as real time digital signal processing.

Because these limitations, if continued indefinitely, would impose severe restrictions on the involvement of NBS staff in the National Measurement System infrastructure, appropriate adaptations are presently planned to acquire the essential test facilities and instrumentation, and to appropriately redirect manpower.

Other identified NBS program weaknesses will give rise to probable changes to the National Measurement System/NBS interaction. These will include an increase in the amount of analytical or basic research concerning the mechanisms of noise generation and transmission, attention to the relationship between structural vibration and acoustic radiation, and consideration of important practical considerations such as specification of sound level meter calibration procedures, attention to electronic aspects of audiometric instruments, and consideration of the relevant psychoacoustic phenomena.

The needs for NBS services are made apparent through contacts directly to NBS from the prospective users, or through indirect means such as requests transmitted through the infrastructure, and as well, through reviews of the requirements of the measurement system such as that underlying this report.

Current NBS resources to meet present user needs appear to be adequate in most respects. Naturally, there are some needs of potential users which cannot be met, because of the absence of desired facilities, but the present facilities and staff are well adapted to most present user needs, and as previously noted, NBS is able to provide many important measurement services. Because of the current and anticipated growth of the noise emission and monitoring as well as the hearing conservation technologies, considerable attention is presently directed toward study and review of the physical basis for and quantitative estimation of inaccuracies in the relevant measurement methodologies. Current NBS capabilities in the evaluation of complex acoustical instrumentation systems appear to be well adapted to these studies.

Ultrasonic nondestructive testing appears to be an example of an emerging technology for which NBS can provide significant leadership in standardization and acoustical measurements. In this case, several industrial representatives and the Air Force Material Laboratory requested NBS to consider the possibility of assuming a more active role in the standardization processes associated with this technology. Also, NBS has been asked by the American Society of Metallurgical Engineers, the American Society for Testing and Materials, the Electrical Power Research Institute, transducer manufacturers, and researchers to develop and disseminate absolute measurement techniques for acoustic emission transducers. It is appropriate that NBS be involved with these topics since the work is closely concerned with the development of test methods, physical properties of materials and products, physical standards, consistency in measurement, and assistance to other government agencies -- all criteria which are embodied in the NBS enabling legislation and its subsequent amendments. In the event that NBS is not able to provide assistance, there are three areas of national concern that will suffer:

--- Competitiveness and productivity of American manufactured products for quality control, unit cost, product improvement, reliability and maintainability. Exported manufactured products from the U.S.A. have often met price competition through better performance and reliability. These advantages are being eroded by technological advances of foreign producers. The absence of carefully evaluated non-destructive testing and evaluation standards and techniques from a nationally recognized source that can be used effectively and economically is denying American industry a potentially powerful tool -- that of reducing hazards to the consumer -- which would help retain and expand export markets.

--- Hazards in consumer products can be reduced significantly by appropriate use of non-destructive testing and evaluation technology. The high costs of the equipment and skilled operators has precluded its use for inspections of the critical components of most consumer products. Traditionally, standardization of devices and procedures has reduced the costs of using sophisticated measurement systems and this is expected to occur here also.

--- Continued reliability of public and quasi-public facilities such as energy transmission systems, transportation equipment, power plants and large structures is clearly in the public interest. Varying levels of monitoring are regularly carried out for these kinds of facilities to anticipate degradation or loss of mechanical integrity with non-destructive testing and evaluation procedures being widely applied. These efforts are seriously handicapped by the lack of an unequivocal physical reference system, i.e., standards, against which observations can be compared.

The current NBS program in acoustics, as has been indicated, includes a wide range of services, from the provision of microphone calibration services to representation of U.S. interests in the international standards infrastructure. In the event that some of these services were to be discontinued there would be a potentially wide range of impacts.

Some of the more routine calibration work might conceivably be obtained at alternate sources, but at some potential sacrifice of the objectivity and tight control of the measurement variables which has characterized NBS services in these fields.

Other services, such as the representation of U. S. interests in the international standards community are important in continuing efforts to assure equity in international trade. In particular, in the event that the international noise control community were to adopt noise measurement methodologies radically at variance with those in the U.S., artificial barriers to international trade might ensue in that product noise emission specifications would not be compatible, with a resulting adverse effect upon purchase of U. S. goods abroad. An important objective of NBS participation in the international standards infrastructure is to ensure not only that the interests of the participants in the infrastructure in this country are appreciated internationally, but that international thoughts on these topics are understood in this country.

Because of the disparate interests of the various segments of the industries concerned with acoustical measurements and noise control, the voluntary consensus system for the development of noise measurement methods has not independently developed many of the required methods and cannot react in an acceptable time frame. Furthermore, NBS participation in the acoustical standards setting infrastructure is necessary since many of the required data bases and test methods could alternatively only be developed by private sector laboratories and consultant firms. In many cases, these organizations are heavily involved in noise abatement work with the industries to be regulated, and conflicts of interest would impair their potential objectivity.

4.5. The Future

Several changes in the services presently provided by NBS appear to be indicated at this time. These changes are dictated largely by realization of the changes taking place within the acoustical measurement portions of the National Measurement System, and are mainly a consequence of the introduction of what was previously termed the legislative imperative. This imperative simply consists of the realization, on the part of those performing acoustical measurements, that acoustical measurements will be required for the implementation of noise control or environmental pollution legislation. Thus, there will be important legislative and economic consequences associated with not only the "end-use measurement data", but with the associated measurement methodologies. Whereas in previous eras the significance of measurement data and of the associated accuracy and precision was often largely an academic concern, the legislative imperative has provided a long overdue motivation for the evolution of improvements in instrumentation, in measurement methodologies, and in the extensions of acoustical measurement services.

Specifically, it appears that three types of improvements in NBS acoustical measurement services are indicated:

--- A program of sound level meter "type certification" should be developed in realization of the increased significance of errors resulting from use of improperly calibrated or functioning sound level meters. Such a program ought to achieve several objectives. At the very least, a calibration service should be provided to verify that an instrument does or does not conform to the appropriate sound level meter specifications. A second objective would be to establish a standard method for acoustical and electronic calibration testing of sound level meters. Finally, another objective would be the improvement of the relevant specification standards. The evolution of such a program is in response to requests and inquiries from regulatory and enforcement agencies, manufacturers, and industrial laboratories, and should greatly help in reducing measurement uncertainty resulting from the instrumentation system.

--- The present NBS program directed toward the study of noise emission measurement, and noise monitoring instrumentation and measurement methodologies must be extended in scope. In particular, the economic and social consequences of measurement imprecision and inaccuracies must be made more apparent to the relevant regulatory agencies, to the standards- setting community, and to the relevant trade associations. Also, attention should be directed to the relevant physical phenomena in order to evolve measurement systems with improved accuracy and precision.

--- It would be appropriate for NBS to participate more fully in the calibration of audiometric equipment than is presently done. Study of the adequacy of acoustical and electroacoustical performance and calibration specifications for these instruments, and participation in measurement assurance programs and calibration round-robins are indicated by considerations of the greatly increased frequency of audiometric testing anticipated as a consequence of hearing conservation programs demanded by current and proposed regulations.

The emerging technology of ultrasonic non-destructive testing and evaluation is an excellent example of an acoustical "measurement-intensive" technology which will require appreciable support from NBS in the future. In particular, it will be important that NBS aid in more precise characterization of reference materials used in this technology, in the provision of calibration services for the ultrasonic transducers used, and in the extension of fundamental physical principles to analysis of the ultrasonic non-destructive testing and evaluation instrumentation.

There are numerous legislative actions that force the provision of these and other related services. These range from the NBS Enabling Act of 1901, to the Noise Control Act of 1972, which authorizes the Administrator of the Environmental Protection Agency to develop improved methods and standards for measuring and monitoring noise in cooperation with NBS, and to proposed legislative or regulatory actions of the future. At present, it appears likely that many more states and municipalities will become active in noise control legislation within the next decade, and it will be important that NBS provide appropriate leadership on the topic of the acoustical measurements required for effective legislative actions and enforcement.

Several actions on the part of NBS to respond, not only to the realization of the needs of changing and emerging technologies, but to the realization of the strengths and weaknesses of the current NBS program in acoustics, are in order. These actions include:

--- Initiation of the above-indicated improvements in NBS services and provision of NBS support to emerging technology.

--- Intensive scrutiny of existing acoustical measurement methodologies with regard to quantitative estimation of the inherent measurement errors and imprecisions, supplemented by studies of the consequences of these errors to the society.

--- Strengthening the current program of basic acoustical research to extend the scope of current activities to include the topics of airborne and structure-borne sound transmission. In order to stimulate this work, it will be necessary to provide essential transmission loss facilities. Laboratory measurements of sound emissions over a reflecting plane in an otherwise anechoic space are not permitted by the present facilities. This important deficiency and limitation on measurement capabilities should be remedied.

--- Finally, the acoustical measurement community, both at NBS and within the larger infrastructure, should be educated as to the structure of the National Measurement System, to the inter-relationships existing within the system, and to the means by which the inadequacies of the system can be remedied.

5. SUMMARY AND CONCLUSIONS

5.1. State of The National Measurement System

The concept of a National Measurement System does not appear to be very widespread or initially comprehensible to many of the actual participants in the system. This is certainly true for those concerned with the acoustical measurements portion of the system. Although it is likely that those involved suspect that there *ought to be* some systematic interrelationship of the bases for all measurement processes, most of those performing acoustical measurements realize that their measurement processes are at best, loosely coordinated. Because all active scientists and engineers are at some time or another concerned with measurement, and require the objective quantitative knowledge that is to be obtained from measurements, they are participants in the National Measurement System. An important objective of the study on which this report is based has been to identify the structure of the National Measurement System for Acoustical Measurements. In so doing, the relevant measurement system elements and the interfaces between these elements and NBS make the system infrastructure more apparent, and technological, social, and economic impacts have been discussed. In the process of defining the system structure, current measurement challenges have been identified and clarified. These data are important factors in the allocation of funds, in the evaluation of current programs in the light of new information and in the prediction of program directions adapted to new needs.

The scope of this report has been principally limited to those acoustical measurement processes which are motivated by increasing societal concern over noise and which are, at the same time, continuations or extensions of traditional acoustical measurements. As an illustrative example of the diversity of acoustics, however, additional material has been presented to describe the technology of ultrasonic non-destructive testing. This technology is directed toward identification of structural flaws, and the measurements are performed in order to meet increasingly severe damands for mechanical integrity, reliability, and pressures for material conservation.

The role of acoustical measurements in our technological society has significantly increased within the recent past not only because of the continuing expansion of technology, but also because of the emergence of a legislative imperative. This imperative grew out of legislative and regulatory actions directed at a reduction of the form of environmental pollution which one author has termed the "tyranny of noise". [63]

Acoustical measurements directly affected by the legislative imperative include the measurement of noise emissions, environmental noise monitoring and those related to the implementation of hearing conservation programs.

Until recently, there was only a limited awareness among the acoustics technical community of the desirability or necessity for inter-consistency of acoustical measurement methodologies, or for close attention to the accuracy and precision inherent to the measurement process. However, the legislative imperative has now intensified awareness of the shortcomings of the measurement system and the potential economic impacts of measurement errors are now being realized.

The nature of the acoustical measurement portion of the National Measurement System is undergoing an evolutionary transition, from a previous state in which the consequences of measurement error were often disregarded, to an improved state in which the consequences of measurement error are often recognized to be intolerable. Increased attention is consequently being brought to bear upon the improvement of measurement systems -- both as systems of instrumentation elements and measurement methodologies and as systems containing individual participants making use of measurement instrumentation and methodologies.

It is therefore an excellent time for participants in the acoustical measurements portion of the National Measurement System to benefit from studies of the relevant interrelationships, to improve the measurement transactions occurring between system elements, and to direct their individual or institutional roles toward the evolution of an improved measurement system.

5.2. Role of NBS Acoustics Activities Within the National Measurement System

The role of the National Bureau of Standards acoustics activities within the infrastructure of the National Measurement System is based primarily upon interactive processes, which constitute the inputs and outputs for these activities. The substance of the interactive process consists of such elements as the provision of and interchange of data pertaining to:

--- transducer calibration services
--- literature reviews
--- data bases
--- development of measurement methodologies
--- development of special purpose instrumentation systems
--- evaluation of instrumentation systems
--- study of the physical phenomena relevant to all acoustical measurements.

Participants in this interactive process include standards organizations, various industrial representatives (including trade associations and individual manufacturers), professional societies and universities, and representatives of foreign laboratories. Because of the increased legislative attention being given to noise and its control, and of the consequent attention to the required measurement methodologies, the adequacy of these methodologies is now the subject of intensive study, both within NBS and within other Federal, State and local agencies.

5.3. Conclusions and Recommendations For Action

The study indicates that there is a continuing demand for improved accuracy and precision both in the development and calibration of acoustical measurement instrumentation and in the evolution of improved measurement methodologies. Provision of services such as these has traditionally been a strength of the NBS program in acoustics.

The study also illustrates that a significant increase in the number and scope of legislative actions directed toward noise control has taken place. It is likely that this increase will continue, particularly as State and local governments become active participants. Inconsistencies in the relevant required measurements are apt to introduce ambiguities into the legislative actions and the imprecisions inherent in these measurements may introduce inequities in trade as well as inhibit expansion of the technology.

A number of elements are suggested for incorporation into the existing NBS program in order to adapt to changing needs of the technical community. These elements include:

--- Thorough study of the effects of environmental factors such as temperature and humidity upon the properties of acoustical measurement systems and system elements. These factors become increasingly important as interest is extended to include acoustical measurements conducted over long time periods.

--- Provision of performance testing services for acoustical measurement systems such as sound level meters. This would include the development of an appropriate test methodology both to verify proper operation and to supplement the present standards on performance specifications.

--- Renewed attention to the electronic and acoustical characteristics of audiometers. The proper calibration, maintenance and operation of this type of acoustical measurement instrumentation will become increasingly important to our society as hearing conservation programs become mandatory and more widespread.

--- Continued attention to the accurate and objective collection of noise emission data bases and to the development of improved acoustical measurement methods. The provision of these services to such users as Federal, State and local regulatory agencies and trade associations will be critical to the equitable enforcement of noise control legislation.

--- Continued interaction with the national and international acoustical measurement standards community. These interactive processes provide an important means for the dissemination of NBS measurement expertise.

--- Strengthening of the NBS program of research in the relevant basic physical phenomena, and the provision of important measurement facilities for this research. The absence, at the NBS Gaithersburg site of semi-anechoic, airborne sound transmission loss, and structure-borne sound test facilities has proven to be a severe handicap, not only to NBS involvement in the infrastructure but also to continued professional growth of the staff. Provision of the facilities will remove barriers which presently stand in the way of the provision of leadership by the National Bureau of Standards in the measurement of important acoustical phenomena.

Based upon the above recommendations, it is the authors' judgement that acoustical research should be directed toward:

--- basic physical phenomena which underlie all acoustical measurements

--- the study and evolution of both improved measurement facilities and instruments which constitute the tools used for measurement

--- the improvement of the required measurement methods which constitute the rules, definitions and procedures by means of which the tools are used for the measurement process.

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APPENDIX A. METHODOLOGY OF THE STUDY

In the conduct of this study of the acoustical infrastructure of the National Measurement System, use was made of a number of complementary sources of data. While the individuals contributing to the preparation of this report each utilized somewhat different methods, there have been some common elements to the various approaches. Basically, the common elements have included:

... *Membership in standards committees and professional societies.* NBS personnel serve on technical committees of the American National Standards Institute, American Society for Testing and Materials, Institute for Electrical and Electronic Engineers, and the International Organization for Standardization. Professional society memberships are held in the Acoustical Society of America, the Institute of Noise Control Engineers, the Institute of Electrical and Electronic Engineers, and the Audio Engineering Society. In addition, close contact is maintained with the Society of Automotive Engineers.

... *Attendance at professional society meetings or special conferences and symposia.* Notably, NBS representatives participated in the previously cited Conference on Acoustics and Societal Problems, sponsored by the Acoustical Society of America.

... *Meetings with trade organization and industry representatives,* such as those listed in table 12.

... *Discussions with personnel in Federal and state agencies,* most notably Department of Transportation, Environmental Protection Agency, General Services Administration, Veteran's Administration, Department of Housing and Urban Development, and the State of California. In many cases, NBS has worked closely with these agencies in a variety of measurement-related tasks.

... *Visits to domestic and foreign research laboratories.* These helped to determine the current status of research activities and international measurement systems. Also, valuable inputs for this study were provided by visits to the facilities of, and meetings with faculty and staff members of several universities.

... *Review of relevant technical literature,* proceedings of technical conferences, and a limited amount of economic market analysis reports dealing with the economics of the noise abatement market.

... *Preparation and review of several informal (limited distribution) questionnaires and correspondence* sent to industry and federal government representatives.

... *Compilation of information* to be used in the preparation of technical reports by NBS personnel provided useful inputs to this report.

... *Daily use, by NBS staff members, of the instruments and instrumentation systems* discussed in this report provided a familiarity with the operating characteristics of the devices, the context in which they are used in a particular measurement methodology, and the inherent strengths and weaknesses which choice of a certain device imposes on the methodology.

APPENDIX B. SUMMARY OF BACKGROUND DOCUMENTS

Document Title: "Acoustic Measurements"
By: L. L. Beranek
Publisher or Source: John Wiley and Sons, Inc. New York, (1949)
Relevance to This Study: This text is the basic reference text on the subject of acoustical measurements, and despite the fact that it is more than 25 years old, it still adequately describes many of the fundamental physical considerations involved in performing acoustical measurements. Detailed information supplementing that contained in this report can be found in this text.

Document Title: "Measures For Noise Abatement" An Issue Study
By: D. R. Flynn and A. I. Rubin
Publisher or Source: NBS Internal Document (1972)
Relevance to This Study: This issue study documents the noise problems in the United States, indicates that improved acoustical measurements are essential for workable solutions to the problem, and indicates reasons why NBS is a well-qualified agency to deal with noise measurement problems. It describes an enlarged NBS program in noise to deal with the problem, outlines the emphasis of this program, and indicates the desirability of construction of new facilities. This is an example of an NBS program review conducted prior to this study.

Document Title: Noise Pollution Abatement Report
By: (Unspecified)
Publisher or Source: Frost and Sullivan, Inc. New York, (1972)
Relevance to This Study: This report documents a private analysis of some of the technological and economic factors involved in noise control problems. It consists of a synthesis of material obtained from a variety of sources, and was useful primarily as as source of economic data.

Document Title: Noise Pollution Control: Report No. 418
By: (Unspecified)
Publisher or Source: Stanford Research Institute Menlo Park, Calif. (1972)
Relevance to This Study: This report documents another private analysis of factors involved in noise pollution control. Its relevance was primarily to provide an overview of the noise control problems.

Document Title: Occupational Exposure to Noise
By: (Unspecified)
Publisher or Source: National Institute for Occupational Safety and Health U. S. Department of Health, Education and Welfare (1972)
Relevance to This Study: This report documents technical and physiological factors supporting the criteria for recommended standards on occupational exposure to noise to be acted upon by the Occupational Safety and Health Administration of the Department of Labor.

Document Title:	Report on the Conference on Acoustics and Societal Problems
By:	J. C. Johnson and A. D. Stuart (eds.)
Publisher or Source:	Acoustical Society of America New York (1972)
Relevance to This Study:	This conference report describes the results of a conference dealing with the topics of: noise and man, outdoor sound propagation and sources, motor vehicle noise, bio-medical acoustics, acoustic applications, and other topics. The conference, made possible through the support of the National Science Foundation, attempted to delineate ways in which the Acoustical Society of America might address problems affecting human welfare. It is useful in its concern for social and technological applications of acoustics.

Government Standards Activities

This is an edited summary of an oral presentation on government standards and regulations by D. R. Flynn of the National Bureau of Standards. This presentation was made on 15 January 1974 at the Arden House Workshop on Noise Control Engineering, Arden House, Harriman, N.Y. — Ed.

This talk discusses some of the noise regulations that presently exist, most of which are fairly recent. Mainly because of my own experience with the Federal Government, this discussion will be a little more heavily slanted toward the Federal regulations. Also, the implications of measurement and measurement standards with regard to the regulations will be discussed briefly.

The regulations that have probably had the most impact so far (mainly because they have been in force slightly longer than some of the others) are the hearing conservation regulations (see Table 1). As originally passed, the Walsh-Healey Public Contracts Act authorized Federal regulation of a number of safety and health requirements having to do with work done under Federal contract, but it was not until 1969 that the Walsh-Healey noise regulation was promulgated. Under the Federal Coal Mine Health and Safety Act of 1969, essentially the same regulations as those under the Walsh-Healey Act, were extended in 1971 to cover the noise exposure of mine workers. The Construction Safety Act extended this coverage to some groups of construction workers. In 1970, after the Occupational Safety and Health Act was passed, these regulations were extended to essentially all workers engaged in interstate commerce.

AUTHORITY	*REGULATIONS PROMULGATED*
Walsh-Healey Public Contracts of 1942	1969
Federal Coal Mine Health and Safety	1971
Construction Safety Act	1971
Occupational Safety and Health Act of 1970	1971
Interstate Commerce Act and Department of Transportation Act	1973

Miscellaneous regulations specific to a given agency's activities have been issued by the:

Atomic Energy Commission
Air Force
Navy
General Services Administration
Army

Table 1. Federal Hearing Conservation Regulations

Under several authorities, specifically the Interstate Commerce Act and the Department of Transportation Act, there have been some recent regulations from the Department of Transportation, Bureau of Motor Carrier Safety, that are also quite similar to the aforementioned ones. All of these regulations utilize the A-weighted sound level and with few exceptions, all the regulations utilize the 5 dB per doubling rule — that is, for every 5 dB increase in level, the allowable exposure time is halved. International standards under ISO use an equal energy rule, corresponding to 3 dB per doubling. In the EPA criteria document and in early drafts of their "levels document" (to be discussed later) a 3 dB per doubling rule is used. With a 3 dB per doubling rule, if 90 dB A were allowed for eight hours, the maximum noise level that would be allowed for 15 minutes would be 105 dB A rather than 115 dB A as allowed under the present OSHA regulation. The particular algorithm selected has significant implications for the technical and economic impact of the regulations. Regulations similar to these have been enacted by other Federal agencies to suit their particular activities.

These hearing conservation regulations have several ramifications in the measurement sense. They have resulted in a proliferation of sound level meters, particularly what is referred to as a Type 2 sound level meter, over the past four or five years, and some of these sound level meters are, candidly, less than satisfactory. They have also resulted in the development of a number of integrating sound level meters or dosimeters, if you will, that attempt to measure a worker's total noise exposure. There are currently performance standards being developed by ANSI on this instrument. In addition, several Federal agencies (Bureau of Mines, Department of Interior; National Institute of Occupational Safety and Health, HEW) have been evaluating these instruments. NBS has evaluated several commercial dosimeters for the EPA and has issued a report giving the test results. There are some real measurement problems with these devices. Hopefully, these problems will be addressed and the situation will improve somewhat in the future. In addition to hearing conservation regulations, there have been a number of other congressional actions over the past few years that have had significant impact (see Table 2). These tend to relate more to authorities for transportation noise. However, the National Environmental Policy Act requires that environmental impact statements be filed in a number of different activities. There have been a number of these on noise — to put in a new highway, a new airport, or any other major construction project, the impact on the environment has to be assessed. To continue further, under Title IV of the Clean Air Amendment of 1970, EPA was authorized to do a study of the noise problem and this resulted two years ago in their report to the President and Congress on noise. The Consumer Product Safety Act of 1972 has implications for some fairly stiff regulations. This Act, in effect, states that for any consumer products where there is a real safety problem the Consumer Product Safety Commission can prohibit the sale of those products. One has to define what one means by safety. This could be a hearing hazard, or in principal, it is possible to have a product sufficiently noisy that there is a danger due to communication interference (for example, if a person cannot hear a warning signal). NBS has been involved in testing some noise-producing toys, particularly cap guns, and in the future will probably test other noise-producing consumer products.

- Transportation Act of 1966
- Aircraft Noise Control Act of 1968
- National Environmental Policy Act of 1969
- Airport and Airways Development Act of 1970
- Urban Mass Transportation Act of 1970
- Clean Air Amendments of 1970
- Federal-Aid Highway Act of 1970
- Noise Control Act of 1972
- Consumer Product Safety Act of 1972
- Federal-Aid Highway Act of 1973

Table 2. Congressional Actions on Noise.

Switching very briefly to the area of aircraft noise, there have been a number of rule-making actions by the Federal Aviation Administration (Table 3). The most notable is the FAR-36 rule which says that new types of aircraft, basically

11-3-69	FAR Part 36:	"Noise Standards: Aircraft Type Certification" effective 12-1-69.
8-4-70	ANPRM 70-33:	"Civil Supersonic Aircraft Noise Type Certification Standards"
10-30-70	ANPRM 70-44:	"Civil Airplane Noise Reduction Retrofit Requirements"
9-13-71	NPRM 71-26:	"Noise Type Certification and Acoustic Change Approvals"
7-7-72	NPRM 72-19:	"Newly Produced Airplanes of Older Type Design"
1-24-73	ANPRM 73-3:	"Civil Airplane Fleet Noise (FNL) Requirements"
3-13-73	FAR PART 91:	"Civil Aircraft Sonic Boom", effective 4-27-73
10-10-73	NPRM 73-26:	"Propeller Driven Small Airplanes"
10-26-73	FAR PART 36:	"Noise Standards for Newly Produced Airplanes of Older Type Designs", effective 12-1-73.

Table 3. FAA Rule-making Actions on Noise.

jet aircraft and subsonic aircraft, must be type certified as to allowable noise under prescribed procedures – the takeoff, landing, and sideline noise. The type certification utilizes a tone corrected, duration corrected, Perceived Noise Level. This has important measurement implications in that it requires fairly accurate third octave band levels and employs a fairly complicated algorithm. As can be seen, there have been several Advance Notices of Proposed Rule-Making and Notices of Proposed Rule-Making in the past few years. The one that is particularly worthy of note (because of the measurement implications) is NPRM 73-26, Propeller Driven Small Airplanes. This is different from previous rule-making actions in that it uses, as a measure, A-weighted sound level rather than a tone-corrected Perceived Noise Level. It was felt that for a propeller plane the correlation between human response and the A-weighted level was adequate enough to justify its use in the regulation. Also, in connection with ANPRM 73-3 (Civil Airplane Fleet Noise Requirements), the Advance Notice of Proposed Rule-Making is now advancing to a Notice of Proposed Rule-Making. This regulation as originally written used a very complicated procedure, sort of an energy weighting of the impact from the whole fleet rather than that of a single airplane. There was so much controversy over this that it has been simplified considerably in the Notice of Proposed Rule-Making.

Under the Noise Control Act of 1972 (Table 4), the Administrator of EPA is authorized, to coordinate Federal programs in noise, to identify major noise sources, to establish noise criteria, and to publish reports about available control

Sec. 4	Federal Programs
Sec. 5	Identification of Major Noise Sources, Noise Criteria, and Control Technology
Sec. 6	Noise Emission Standards for Products Distributed in Commerce
Sec. 7	Aircraft Noise Standards –Study –Standards and Regs –FAA Act Amended
Sec. 8	Labeling
Sec. 9	Imports
Sec. 14	Research, Technical Assistance, and Public Information
Sec. 15	Development of Low-Noise Emission Products
Sec. 17	Railroad Noise Emission Standards
Sec. 18	Motor Carrier Noise Emission Standards

Table 4. Noise Control Act of 1972

technology. In July, EPA published their "criteria document," and currently are working on a levels document. *(The "levels document" was issued in early April – Ed.)* In the "levels document" they are putting forth levels, independent of technological and economic considerations, that would assure protection of public health and welfare.

Section VI of the Act, which may have very significant implications for the whole country, allows EPA to set noise emission standards for new products distributed in commerce. Essentially this says that if a product makes more than a certain noise level as determined by a certain measurement methodology, it cannot be sold. EPA should announce shortly the first few products *(See the Federal Register for 21 June 1974 – Ed.)* to be regulated under this section of the Act. NBS is working with EPA closely on the development of appropriate measurement methodology, and certainly this has to include not merely how the acoustic measurements are made but what the device under test is doing, what sort of operation it is undergoing while you're making the measurement, how it is installed, etc.

Under Section VII, EPA has authority in the area of aircraft noise standards. In particular, the Federal Aviation Act has been amended to permit EPA to study the problem and then recommend standards and regulations to the FAA. Without going into detail, some of the areas under consideration include takeoff and approach procedures, minimum altitude procedures, type certification of aircraft, fleet noise levels, retrofitting of existing aircraft, the supersonic problem, and possible modifications to the present regulations (FAR 36). Also, EPA will be considering questions concerning propeller plans (in addition to jet planes), the R/STOL and VTOL aircraft, and the whole question of airport noise regulations (see Table 5 for a summary of these).

1. Takeoff Procedures	Operating Procedures
2. Approach Procedures	Operating Procedures
3. Minimum Altitude Procedures	Operating Procedures
4. Retrofit/Fleet Noise Level (FNL)	Type Certification
5. Supersonic Civil Aircraft Noise	Type Certification
6. FAR 36 Modifications	Type Certification
7. Propeller Driven Aircraft	Type Certification
8. Reduced or Short Takeoff or Landing (R/STOL)	Type Certification
9. Vertical Takeoff or Landing (VTOL)	Type Certification
10. Aircraft Noise Regulations	Type Certification

Table 5. Aircraft/Airport Noise Regulatory Actions

Under Section VIII of the Noise Control Act, the Administrator is authorized to require labeling of products where the noise impact is not sufficiently severe to prohibit sale of the product, but severe enough that an indication of the noise emission from that product is needed. The measurement implications here are quite severe; how is a product labeled so that it provides sufficient information to the ultimate consumer and is still simple enough that the majority of persons will understand it? How can the noise of different types of products be compared? Do you use actual decibel levels or do you give simpler A, B, C, D type categories, etc? It gets to be very difficult to know just how to do this, particularly with other Federal agencies coming out with labeling systems for other product attributes besides noise. If not well-planned and thought out, the communication that is desired will be totally lost.

In Section XIV, EPA is authorized to carry out rather complete activities in the area of research, technical information, technical assistance to states, local governments, etc., and public information.

The effectiveness of Section XV depends on how strict EPA is willing to be about it. This Section authorizes the General Services Administration, in Federal procurement actions, to pay a premium price of up to 25% for certified low-noise emission products. This could have some leverage on the development of low noise emission products.

Sections XVII and XVIII were put in by Congress rather late in the progress of the bill. They regulate interstate carriers and require EPA to set noise emission standards for both railways and interstate motor carriers. Both of these have preemption provisions and there is a lot of concern as to how these may or may not go along with state regulations that have been passed in recent years.

All of these activities have fairly severe and complicated measurement requirements and NBS is trying to work closely with EPA to address a number of these points. It is quite a large task, and EPA is under a great deal of pressure to get a lot of work done in a very short period of time.

In addition to specific regulations, there are other Federal activities that are not really of a regulatory nature, but have serious implications as far as their impact on the economy (see Table 6). These have to do with Federal procurement activities. For instance, for jackhammers, impact wrenches

HUD	Policy
FHWA	Standards
GSA	Procurement
EPA	Low Noise Emission Products

Table 6. Federal Procurement Activities Relating to Noise.

and other such equipment, GSA is buying them now to perform to standards which, among other things, have noise emission requirements. There is also a joint NBS-GSA program where NBS is investigating performance specifications for power lawn mowers and room air conditioners with the thought to buying them with a price premium given for low noise emission products.

In Table 7, it can be seen that HUD has had, under their Federal Housing Administration, some regulations and requirements related to obtaining Federal housing grants. For instance, to obtain an FHA guaranteed loan or mortgage,

HUD
- Federal Housing Administration
  - –Proximity to Airports
  - –Minimum Property Standards
- Departmental Policy

GSA
- Public Building Service

DOD
- Tri-Service

Table 7. Federal Requirements on Acoustical Characteristics of Buildings.

there are requirements concerning housing in the proximity of airports, as well as minimum property standards relating to, for instance, the noise isolation required between dwellings in multiple family situations. Their departmental policy will be discussed below.

General Services Administration has issued performance standards under their Public Building Service requiring that any building built for the Federal government must meet certain criteria. The acoustical criteria could be NC requirements in buildings, noise isolation between rooms within buildings, etc. Similarly, the Tri-Service Group within the Department of Defense has regulations on buildings that would be procured with DOD funds.

The Department of Housing and Urban Development, in Departmental Circular 1390.2, gives standards for the external noise exposure at new construction sites. Essentially, these say that you cannot get Federal funds or Federal guarantees (either through a grant program or guaranteed loan program) unless the noise exposure at a new construction site meets certain criteria. Table 8 lists these criteria.

"UNACCEPTABLE"
Exceeds 80 dB A for 60 Mins./24 Hrs.
Exceeds 75 dB A for 8 Hrs. / 24 Hrs.
Exceeds CNR 115.
Exceeds NEF 40.

"NORMALLY UNACCEPTABLE"
Exceeds 65 dB A for 8 Hrs. / 24 Hrs.
"Loud Repetitive Sounds".
Between CNR 100-115.
Between NEF 30-40.

"NORMALLY ACCEPTABLE"
Does not exceed 65 dB A for 8 Hrs. / 24 Hrs.

"ACCEPTABLE"
Does not exceed 45 dB A for 30 Min. / 24 Hrs.

HUD 1390.2

Table 8. External Noise Exposure Standards for New Construction Sites.

The circular states that the site is unacceptable if the noise level exceeds 80 dB A for 60 minutes out of 24 hours, or 75 dB A for eight hours, and, if it is near aircraft, if it exceeds a CNR of 115 or an NEF of 40. If a site is unacceptable, it requires a waiver signed by the Secretary of Housing and Urban Development if it is to be considered. A key division between "normally unacceptable" and "normally acceptable" is whether or not the noise level at a site exceeds 65 dB A for eight hours out of 24. To determine compliance with this requirement, has certain measurement implications. For instance, an individual from New York who did the required measurements stated that he used a tape-recorder and sound level meter, and taped the noise for 24 hours, usually using fairly high recording speeds and small reels of tape, thus requiring frequent tape changes. He said he took out a professional, a technician, and also, for any place in New York, an armed guard. As a consequence, to get 24 hours of data, it took about nine man days of labor, and probably another three man days to analyze the analog tapes. So, as can be seen, it is a difficult and expensive problem. As a result, NBS has been heavily involved with HUD in developing black box instrumentation that can be strapped on a telephone pole and, at the end of 24 hours, be retrieved with all the necessary data there.

In addition, HUD has interior noise exposure standards (Table 9). These relate both to new construction and to

"ACCEPTABLE"
Sleeping Quarters:
Does not exceed 55 dB A for 60 Min. / 24 Hrs.
Does not exceed 45 dB A for 30 Min. during 11 PM - 7 AM
Does not exceed 45 dB A for 8 Hrs. / 24 Hrs.

Other Interior Areas:
At discretion of HUD personnel.

HUD 1390.2

Table 9. Interior Noise Exposure Standards for New and Rehabilitated Residential Construction.

rehabilitation of existing housing. The key requirement here is that calling for less than 45 dB A for all but 30 minutes during the night or not exceeding 55 dB A for more than 60 minutes out of 24 hours. In some areas this would be very difficult to comply with. Some of the instrumentation NBS has been developing for HUD also can make these measurements just by the flip of a switch.

The Federal Highway Administration has similar requirements relating to Federal assistance (see Table 10). These requirements relate to land use, ranging from areas where "serenity and quiet are important," to residential areas, down through developed lands, undeveloped lands (where they do not have any criteria), to building interiors. The unit of measure is A-weighted L_{10}, the noise level ex-

LAND USE	NOISE LEVEL
Serenity and Quiet are Important	60 dB A
Residences, Schools, Hospitals, etc.	70 dB A
Developed Lands, Other than above	75 dB A
Undeveloped Lands	--
Building Interiors	55 dB A

*Ten-Percentile Level, A-weighted.

FHWA PPM 90-2

Table 10. Highway Design Noise Levels.

ceeded 10% of the time. Essentially, Federal funds cannot be obtained if the levels for the different land uses are exceeded, and since most of the major highways are 90% Federally funded, this has severe economic implications. Since there is no such thing as an L_{10} meter, the measurement problems are a bit tricky using existing conventional instrumentation. Also, there are measurement problems due to the weather since many of the instruments cannot be left outside for 24 hours without damage from the elements.

With regard to the State regulations, these change so rapidly that it can only be hoped that they are current within the last year or so. Many of the states have established limits on the noise emitted from a vehicle during typical operations. For example, the State of California has regulations governing (1) motor vehicles over 6,000 lbs., (2) motor cycles, and (3) other motor vehicles, specifically lighter vehicles (see Table 11). Concerning the sale

OPERATED VEHICLES:

	Speed Limit < 35 MPH	Speed Limit > 35 MPH
(1) Any motor vehicle with gross weight rating of 6,000 pounds or more –		
Before 1-1-73	88 dB A	90 dB A*
After 1-1-73	86 dB A	90 dB A
(2) Any motorcycle	82 dB A	86 dB A
(3) Any other motor vehicle	76 dB A	82 dB A

*Measured 50 feet from center of travel line under any condition of operation.

Table 11. California Motor Vehicle Noise Limits.

of new vehicles, many of the States and some of the cities are issuing regulations in sort of a programmed de-escalation if you will. By way of comparison in Table 12, California, Chicago, Boston all start out at about the same level, and end up at about the same level, but they get there by slightly different means. The implications for the industry here are quite severe in terms of their lead time to produce new vehicles. Table 13 gives a compilation of some of the State transportation noise regulations. The X's show in what areas these states have transportation noise regulations. California has a rather unique regulation on airport noise which will be discussed below.

Class	California	Chicago	Boston
MOTORCYCLES:			
Until 1-1-73	88 dB A	88 dB A	88 dB A
After 1-1-73	86	86	86
After 1-1-75	80	84	84
After 1-1-77	75	75	75
LIGHT VEHICLES			
Until 1-1-73	86 dB A	86 dB A	86 dB A
After 1-1-73	84	84	84
After 1-1-75	80	80	80
After 1-1-77	75	75	75
HEAVY VEHICLES:			
	(6,000#)	(8,000#)	(10,000#)
Until 1-1-73	88 dB A	88 dB A	88 dB A
After 1-1-73	86	86	86
After 1-1-75	83	84	84
After 1-1-77	80	75	75

Table 12. Noise Limit Comparisons — New Motor Vehicles.

	Vehicle Operation	Vehicle Sales	Snowmobile Operation	Snowmobile Sales	Air-Ports
California	X	X	--	--	X
Colorado	X	X	X	X	X
Minnesota	X	X	--	--	--
Connecticut	X	--	X	--	--
Indiana	X	--	--	--	--
Pennsylvania	X	X	--	--	--
Idaho	--	--	--	--	--
New York	X	--	--	X	--
Montana	--	--	--	X	--
Massachusetts	--	--	X	X	--

Table 13. State Transportation Noise Regulations.

California, in its standard on airport noise, uses A-weighted levels which are converted into a Single Event Noise Exposure Level (SENEL) which is sort of the integral under the curve for a single fly-by. This is converted into an hourly noise level which is an energy-weighted average over an hour. Daytime, evening, and nighttime weightings are applied to yield a 24-hour Community Noise Exposure Level (CNEL). This value can be converted to an annual community noise exposure level, where you take the CNEL average over an entire year. (See Table 14 for a summary of this discussion.) The implications for the measurement procedure have to do with instrumentation. A fair commitment of instrumentation is required. There are instruments coming out to measure these values, but there are no performance specifications at the present time. ANSI is looking at these instruments and is trying to develop performance requirements for the instrumentation. One reason that this is much more important than it might

Definitions:

(1) Noise exposure level (NEL) – accumulated noise level, A-weighted Level (in dB re 20μN/m^2 and 1 second).

(2) Single event noise exposure level (SENEL) – NEL of a single event (flyover).

(3) Hourly noise level (HNL) – Average noise level over an hour

$$HNL = 10 \log (1/3600) \Sigma \text{ antilog } (SENEL/10)$$

(4) Daily community noise equivalent level (CNEL) - Average noise level over a day, with evening and night periods weighted.

$$CNEL = 10 \log (1/24) [\Sigma \text{ antilog } (HNLD/10) + 3 \Sigma \text{ antilog } (HNLE/10) + 10 \Sigma \text{antilog } (HNLN/10)]$$

WHERE HNLD = HNL, 0700-1900
HNLE = HNL, 1900-2200
HNLN = HNL, 2200-0700.

(5) Annual community noise equivalent level (annual CNEL) – average noise exposure over a year.

$$\text{Annual } CNEL = 10 \log (1/365) \Sigma \text{ antilog } (CNEL/10)$$

Table 14. California Noise Standards for Airports.

initially appear is that EPA is considering using very similar methodology in their levels document. There is concern in having the EPA regulations on specific sources be compatible with the California regulations. This might mean for instance, that if you wanted to rate the noise level of an automobile, you might want to have an energy averaged level over a typical operating cycle so that you can project hourly noise exposure levels. Then, by knowing the amount of hours cars operate, you could ultimately predict community noise exposure levels. Thus, there are many implications for the measurement procedure that will require investigation.

Table 15 is a summation of local transportation noise regulations. Vehicle operation and vehicle sales are sort of grouped together because many of the cities have different regulations. There are a number of other cities that have general (specific sound level requirement) regulations somewhere in the ordinance.

City noise regulations have an interesting history. Some years ago, in the zoning area, all of our regulations were more of a nuisance type regulation. It was a general "thou shalt not commit noise" sort of commandment that people were supposed to comply with. Then in the mid-50's, the Armour Research Foundation came out with an octave-band zoning sort of regulation that was adopted by a number of cities and that is reflected in the statistics in Table 16. In recent years there's been more and more of a trend toward A-weighted sound levels and, as can be seen under motor vehicles and aircraft, everything is in terms of A-weighted sound levels.

	Vehicle Operation	Vehicle Sales	Snowmobiles and/or Off-Road Vehicles	Powered Boats
Chicago	X	X	X	X
Boston	––	X	––	––
New York City	X	––	––	––
Minneapolis	––	X	––	––
Oahu	X	––	X	––
Washington, D.C.*	X	X	––	––

*Proposed

Other Cities with General (Quantitative) Vehicle Noise Laws:

Ann Arbor, Mich.	Walla Walla, Wash.
Pocatello, Idaho	Seattle, Wash.
Idaho Falls, Idaho	Pullman, Wash.
Cincinnati, Ohio	Ancorage, Alaska
Omaha, Nebraska	Boulder, Colorado
	Peoria, Illinois

Table 15. Local Transportation Noise Regulations.

NOISE REGULATIONS

	dB A	dB C	Linear	Octave Band	Octave Band & dB A	Totals
Zoning	24	2	––	34	12	71
Vehicle	21	––	––	––	––	21
Aircraft	4	––	––	––	––	4
Building	1	1	1	2	––	5
Totals	50	3	1	36	12	101

Table 16. City Noise Regulations: Specified Noise Measurement Method (from: Bragdon, C.R., Municipal noise ordinances, Sound and Vibration 7 (12), 18 (December 1973).

With regard to building codes, New York City has had a noise regulation in their building code for several years. Chicago, if they have not already, is about to implement some noise control regulations in their building codes. And that seems to be the trend. There is a definite leaning toward A-weighted levels but there is beginning to be a consideration of the temporal aspects of noise. In the case of HUD, the level exceeded eight hours a day, or the amount of hours that 65 dB A is exceeded is the quantity being measured. In the case of the Federal Highway Administration, it is L_{10}, the level exceeded 10% of the time. In the case of California and some of the EPA regulations, weighted averages over long periods of time are investigated. There is some interest, of course, in the more complicated measures such as Robinson's Noise Pollution Level from England, that takes into account not only the mean level or energy average level, but some measure of the variation of the level with time.

Finally, in addition to moving sources, Chicago, Boston, New York City and others, are attempting to enact noise regulations on stationary equipment, construction equipment for example.

That, in general, is an overview of some of the things that are happening in the area of noise regulations. As mentioned previously, it has tended to dwell more on the Federal regulations than on the State and local regulations. There is a definite trend that one can see, toward using A-weighted sound levels. Some specific measurement requirements on instrumentation are becoming apparent, and as the regulations begin to encompass stationary sources, measurement methodology that adequately measures the noise emission from a product in a way that will correlate with the community response will need to be developed and verified.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes acoustical measurement processes which are motivated by societal concern over noise and which have broad relevance to our contemporary technological society. The emphasis of this study of the National Measurement System for Acoustics has been to review the status of the system in order to determine the adequacy of these important physical measurements and to promote improvements within the measurement system. The relevent physical quantities are indicated, and the interactions occuring between participants as well as the roles of acoustical standardization institutions are specified. Technological, social and economic impacts are outlined. Finally, the status and trends of the system and the NBS role in adapting to changing technology are discussed.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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