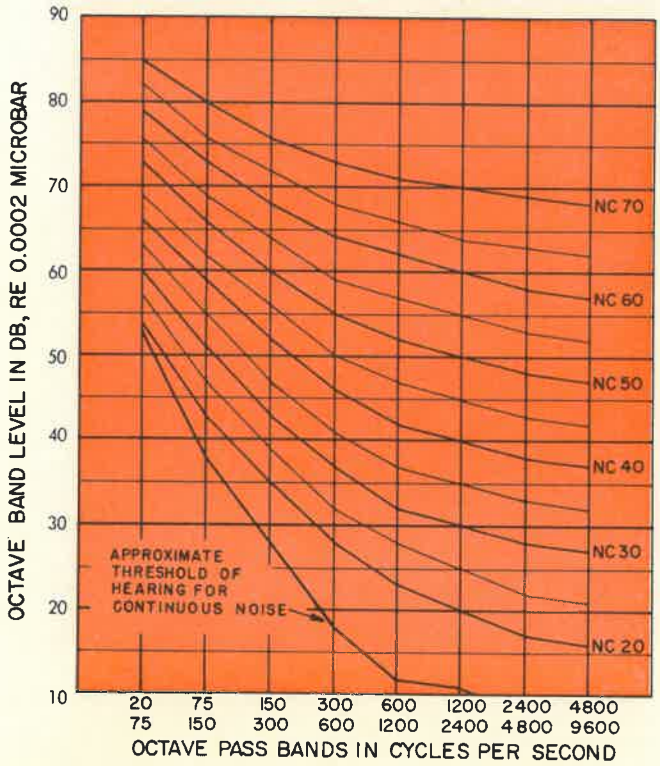

Fig. 1 – Noise criteria (NC) curves, showing maximum tolerance sound levels for the spaces tabulated in Table I.

TABLE I

RECOMMENDED NOISE CRITERIA

Type of Space	*Noise Criterion*
Broadcast Studios	NC 15-20
Concert Halls	NC 20
Legitimate Theater (500 seats)	NC 20-25
Executive Office	NC 20-30
Conference Room for 50	NC 20-30
Music Rooms	NC 25
School Rooms	NC 25
TV Studios	NC 25
Apartments and Motels	NC 25-30
Assembly Halls (amplification)	NC 25-30
Homes (sleeping areas)	NC 25-35
Conference Room for 20	NC 30
Motion Picture Theater	NC 30
Hospital	NC 30
Churches	NC 30
Courtroom	NC 30
Libraries	NC 30
Private and Semiprivate Offices	NC 30-35
Industrial Business Offices	NC 35-40
Large Engineering and Drafting Rooms	NC 40-50
Restaurants	NC 45
Coliseums (sports)	NC 50
Secretarial and Accounting Areas	NC 50-55
Factories	Above NC 55

How to Eliminate Noise from Air Handling Systems

ACOUSTICAL TREATMENT of air handling equipment in residential, commercial, and industrial buildings provides significant benefits for both owners and tenants. With published data available on the sound created by most air conditioning equipment, or readily obtainable from theoretical considerations or actual tests, appropriate noise control measures can be incorporated in the basic system design in complete compatibility with the architectural treatment.

CE exclusive

Establishing Design Objectives

Comfort and the ability to communicate are the prime criteria in setting up allowable noise levels for air handling equipment. However, comfort is a condition for which there is little numerical data. Several engineering groups have made an effort to establish acoustical limits in terms of decibels. What these limits actually signify is not clear, but experience indicates that most of the acoustical criteria are upper tolerance limits. They do not necessarily reflect the most desirable condition, but at least they do establish acoustical limits for large groups of people under actual noise conditions, as shown by studies in a large number of communities. A typical set of acoustical limits is shown in Fig. 1, in the form of curves. The curve applicable to a particular situation is obtained from Table I. The use of these design aids is detailed in the 1960 American Society of Heating, Refrigerating, and Air Conditioning Engineers Guide.

Under the quiet background conditions found in some modern buildings with sealed windows, care must be exercised in selecting design objectives. Some owners and tenants will ask for extremely low air con-

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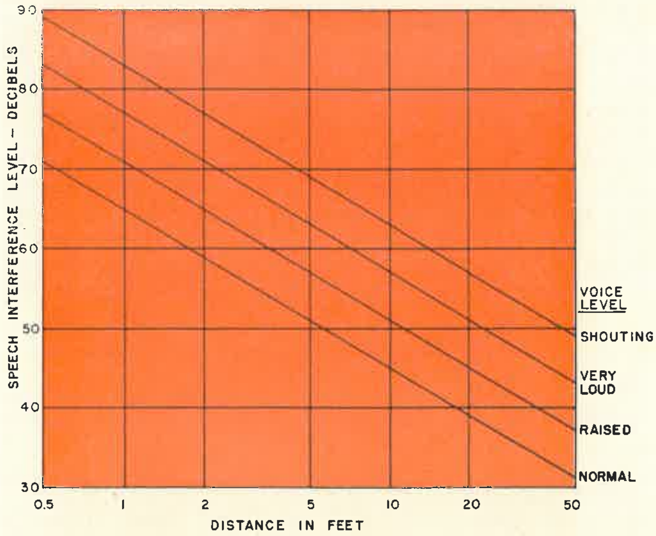

Fig. 2 — Relationship between speech interference level and distance over which communication can be maintained.

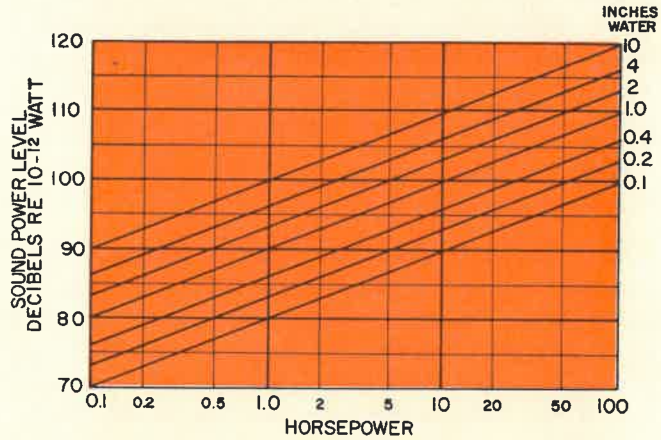

Fig. 3 — Sound-power level of fans as a function of the rated hp of the motor and static pressure across the fan.

ditioning noise levels, while others prefer a higher, masking noise from the air conditioning system. The acoustical engineer must evaluate the situation and meet the exact needs of his client, whether expressed vaguely as "no more noise than in our present offices" or precisely in detailed acoustical specifications.

The ability to communicate is closely related to the effectiveness of a noise in preventing reliable communications over specified distances. Other factors which affect the reliability of communications are the voice level of the speaker, the familiarity of the auditors with the vocabularly used, and the associative responses evoked, by both the noise and the vocabulary, on the part of the auditor. Speech interference is particularly affected by sound energy in the frequency range from 600 to 4800 cycles per second, and a term "speech interference level" is defined as the arithmetic average of the decibel values of the sound pressure level in the bands 600-1200, 1200-2400, and 2400-4800 cycles per second.

Fig. 2 is a chart of speech interference level, as it affects reliable speech communication over various distances. Where safety is dependent on reliable communications using restricted vocabularies, a somewhat higher speech interference level may be tolerated. However, these situations are so specialized that the maximum permissible levels should be determined by specific studies.

The Sources of Noise

The sources of noise in an air conditioning system are not all in one place. The most obvious source is the fan itself. In addition, the distribution system presents problems at the intake grille or louver, at duct joints, at bends, and at the supply and return openings in the conditioned space. Noise also is generated by the fan motor, dampers, fire dampers, and the motion of the air itself when moving at high velocities (2000 fpm and higher). Several other components create noises that are objectionable in areas near the air conditioning equipment room. The cooling tower is the most offensive item of outside equipment.

To provide a point of departure for system design, the sound output values for various sources must be available. These can be expressed as equations or plotted as curves. Fig. 3 is a plot of the well known fan noise equation (correct to within ± 4 decibels over a wide range of sizes and types). The sound power level output is expressed in terms of

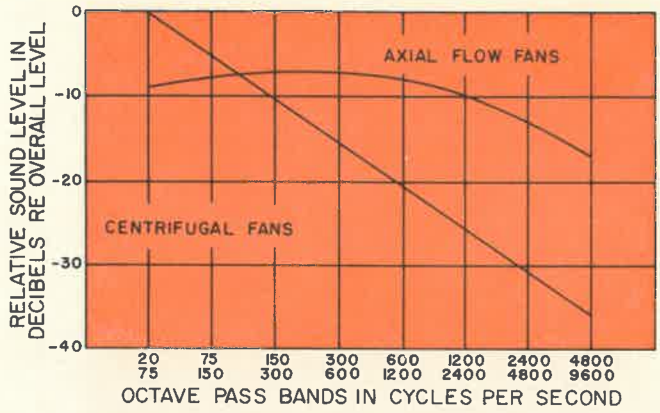

Fig. 4 — Sound levels of general fan types. Sound-power levels of different types are determined by measurement.

rated horsepower of the motor and static pressure across the fan in inches of water. The distribution of sound energy with frequency (spectrum) for two common types of fans is shown in Fig. 4. Fig. 5 shows the noise levels caused by typical rectangular grilles at various velocities and a round diffuser at two settings. From these data, and that now available from most of the quality diffuser and fan manufacturers, it is possible to determine the total noise power available for distribution and radiation by the duct system.

The Transmission of Noise

The noise that is generated by a system travels through a duct or network of ducts and then is radiated into the quiet space or spaces. In the path from source to auditor, the noise is sometimes amplified and sometimes attenuated. It will be amplified if the wave length corresponding to the fundamental fan blade frequency is twice any dimension of a duct in the system. Attenuation can take place at bends, through plenums, and through duct walls. The amount of sound energy removed will be greatly increased where walls of the ducts, bends, and plenums are lined with a medium density glass or mineral fiber acoustical blanket or board. It is interesting to note that a long duct of sizable cross section with several bends will absorb a considerable amount of noise, even if not lined.

In addition to the natural attenuation by ducts and duct lining, a certain amount of sound energy is reflected back toward the fan from the open end of small ducts. The reduction provided by end reflection is shown in Fig. 6. Table II shows the reduction provided at duct branches. All of the various sound energy losses stated in decibels can be added and this total loss subtracted from the initial sound level at the fan. In addition, a loss in sound level occurs as the sound power is distributed throughout the room that a duct supplies. In general, the farther from the duct an auditor stands, the lower will be the sound level. These losses are presented in Fig. 7. Subtracting the proper distance loss from the level at the end of the duct gives the sound level at the auditor's position. The resulting figure is compared to the design objective. If it is lower than the design objective, no additional treatment is required; if it is higher, sound traps, additional duct lining, plenums, or a change in equipment may be required.

A simple illustrative problem based on a research laboratory ventilating system is shown in Table III and Fig. 8.

In designing control measures, it is often expedient to use, near the fan, a plenum with a lining tuned

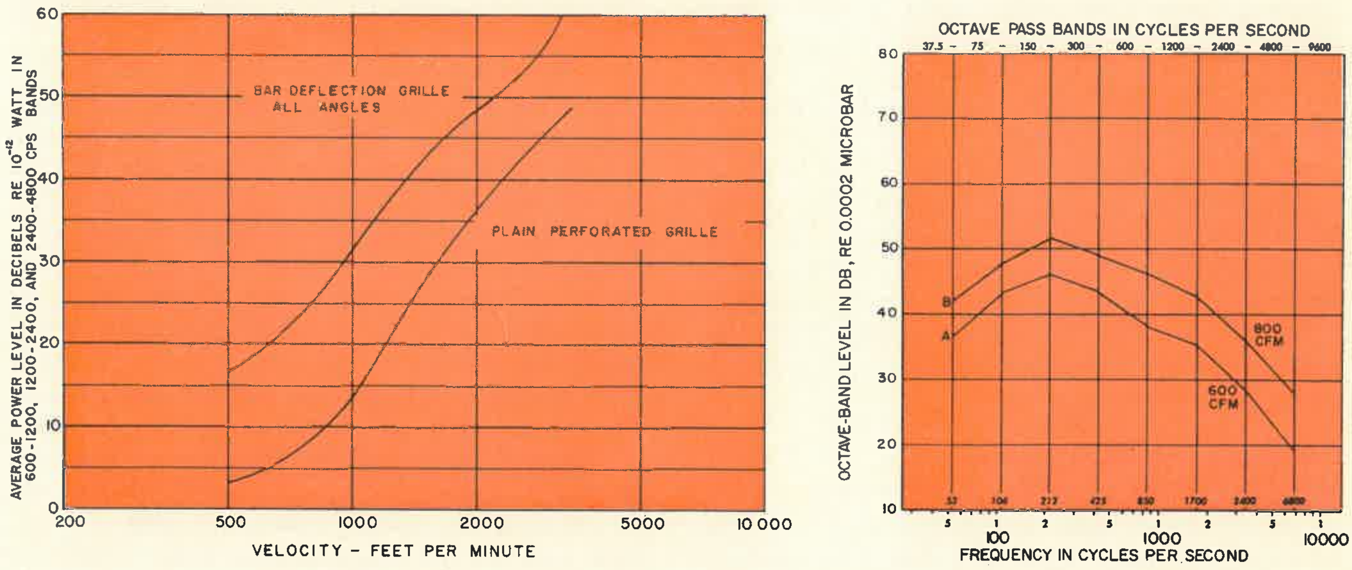

Fig. 5 — Left, sound levels for typical rectangular grilles. Right, sound level 6 ft from 18 in. round ceiling diffuser.

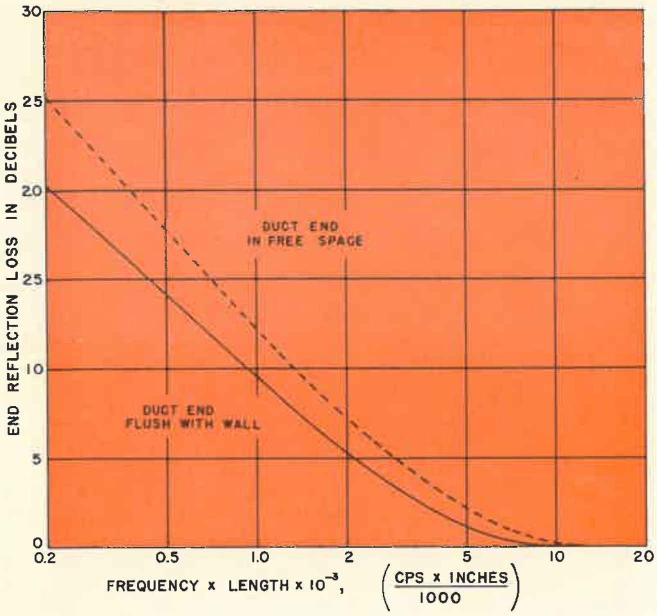

Fig. 6 — Noise reduction by reflection at open duct end. "Length" equals the square root of the cross-section area.

TABLE II

POWER LEVEL REDUCTION AT DUCT BRANCHES

Ratio: Branch Duct Area / Sum of all branch ducts but not supply duct	*Reduction decibels*
1.0	0
0.8	1
0.63	2
0.5	3
0.4	4
0.32	5
0.25	6
0.2	7
0.16	8
0.13	9
0.1	10

to remove low frequency fan noise. Simultaneous provision of unlined 90 degree elbows for the attenuation of high frequency sound will handle most problems satisfactorily. The remaining high frequency attenuation should be provided near the duct discharge, where it can remove high frequency noise generated by both the fan and the distribution system.

Treatment near the discharge also can be used to limit crosstalk between rooms. However, it is sometimes necessary to treat crosstalk as a completely separate problem and to design sound traps or special duct sections for use between rooms supplied from the same main duct. This is often necessary for music suites in schools, in conference areas, and in courthouse and office buildings.

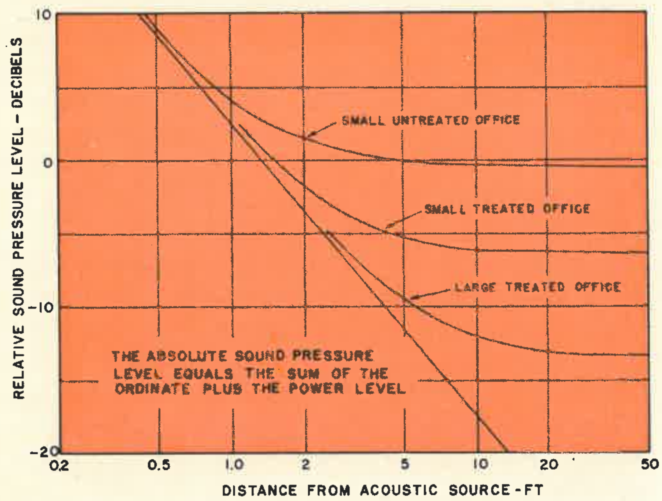

Fig. 7 — Sound-power levels as a function of the distance from the acoustic source, for offices of different sizes.

Noise in Outside Areas

There are many areas not supplied by the air conditioning system that can be affected by noise from the equipment. These include areas adjacent to the equipment rooms and in the neighborhood of the cooling tower. There are four ways that sound energy can travel from the equipment room to other spaces without traveling down the duct and out through a supply or exhaust opening:

¶ Through leaks in the walls of the equipment room.

¶ Through the wall of the duct as it passes through or over the ceiling of a quiet space.

¶ Through the walls of the equipment room.

¶ Through direct mechanical excitation of the building structure by mechanical forces which are developed within the equipment.

Taking these in reverse order, it is possible to provide vibration isolation equipment, inertial block bases mounted on isolators, and isolated floors as brute force approaches to the problem of eliminating mechanical vibration. Additional solutions involve the use of nonvibratory equipment and the relocation of equipment supports to obtain maximum effectiveness from the isolators. One example is the substitution of absorption refrigeration equipment for centrifugal and reciprocating equipment. Where piping is carried on hangers supported from the slab above, relocation to resilient wall hangers and the introduction of flexible piping on both sides of a

TABLE III

NOISE CONTROL CALCULATIONS FOR A RESEARCH LABORATORY VENTILATING SYSTEM

	Octave Bands — cps							
	20 75	75 150	150 300	300 600	600 1200	1200 2400	2400 4800	4800 10,000
1. L_w, Centrifugal Fan, A (10 HP, 2" Water Pressure Static)	103	98	92	87	82	77	72	67
2. Split at B	3	3	3	3	3	3	3	3
3. Split at C	5	5	5	5	5	5	5	5
4. Split at D	3	3	3	3	3	3	3	3
5. End loss at E	12	8	4	1	—	—	—	—
6. Total Reduction	23	19	15	12	11	11	11	11
7. L_w at Grille	80	79	77	75	71	66	61	56
8. Reduction to L_p at 7 feet	–6	–6	–6	–6	–6	–6	–6	–6
9. L_p at 7 feet Small Treated Office	74	73	71	69	65	60	55	50
10. Criteria NC-35	63	55	47	41	37	35	33	32
11. Reduction required	11	18	24	27	28	25	22	18
12. Reduction by package duct muffler	15	17	25	45	55	55	55	50

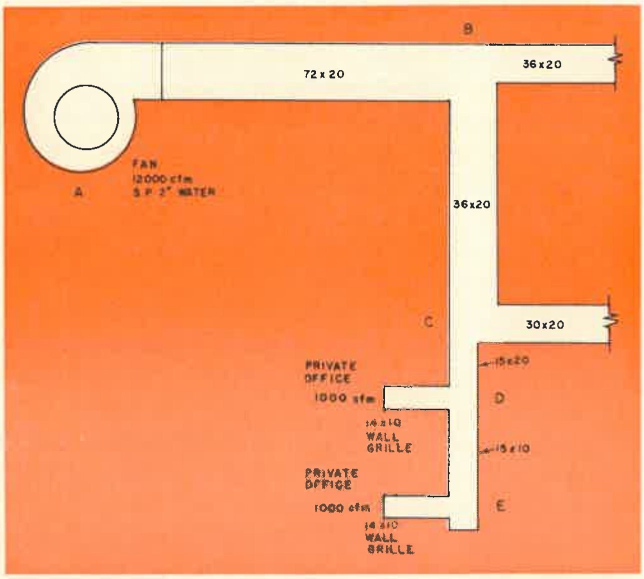

Fig. 8—Schematic diagram of the research laboratory ventilating system used in the calculations shown in Table III.

right angle turn can reduce the vibration transmitted to the first floor from a basement installation.

Mere inclusion of vibration isolation in the specifications and on the drawings will not necessarily prevent excessive noise and vibration. The isolation techniques required are not always understood by the manufacturer. They vary from job to job, and the provision of a standard isolator on all machines is an invitation to trouble. Unless isolators are sized for the particular machine, weight distribution, and floor or foundation conditions, they may be useless.

Air conditioning ducts that have sound isolation just ahead of the outlet to the conditioned spaces often contain considerable sound energy, some of which is radiated through the walls of the ducts. Where these ducts pass through or over a room, they can radiate considerable amounts of noise into the room. This is especially true where the ducts pass over a room with a conventional suspended acoustical ceiling. Sheet metal ducts of 22 gauge galvanized steel have an attenuation characteristic as shown in Fig. 9. This means that the sound level in the room can be estimated by subtracting the duct wall attenuation shown in Fig. 9 from the sound power level in the duct, and converting the result to sound pressure level using the distance factor in Fig. 7.

Here again, acoustical isolation is recommended where the levels in the space exceed the design objective for that space. The isolation can be in the form of a metal lath and plaster enclosure of the duct, a plaster ceiling to which the acoustical tile can be cemented and above which the duct can run, or reduction of the noise entering the duct as it passes into the space above the room.

Equipment room walls must be designed to satisfy design objective noise levels in adjacent spaces.

Where adjacent spaces are store rooms, machine shops, kitchens, or other service areas, the wall construction usually is not critical. However, in many office buildings tenant air conditioning equipment is located on the same floor as the conditioned space. It may be adjacent on six sides to nonconditioned areas having low design objective noise levels, and perhaps not occupied by the tenant in the conditioned space. Under these circumstances, sufficient wall, floor, and ceiling isolation for air-borne noise must be provided or psychological and legal problems will arise to plague both owner and tenant.

Care must be taken to make sure that the sound leakage into these spaces does not negate all of the other sound isolation measures employed. Leaks around ducts as they pass through a wall, particularly a double wall, permit sound to travel into quiet spaces. Sound also sneaks out through pipe openings. A handsome escutcheon plate around a pipe, as it passes through a hole twice the diameter of the pipe, may be aesthetically pleasing, but it does nothing to impede the flow of sound through the hole. Similarly, pipe and duct chases that terminate in the equipment room should be examined for leaks at other floors. Access doors that do not fit tightly will allow enough sound to leak into an otherwise quiet space to destroy the effectiveness of isolation in the ducted portion of the system.

This type of leak can be prevented if special notes are placed on all shop drawings indicating the size of holes for all services, and if the specifications require that all holes be packed with a suitable fibrous filler such as glass fiber wool. A topping of nonhardening high temperature cement must be specified for around heated pipes and a regular nonhardening cement for other pipes and conduit. In some locations it may be convenient to require a sleeve to be cast in place, cemented, or nailed to the structure, and the pipe, conduit, or duct run through, with the space between packed and sealed.

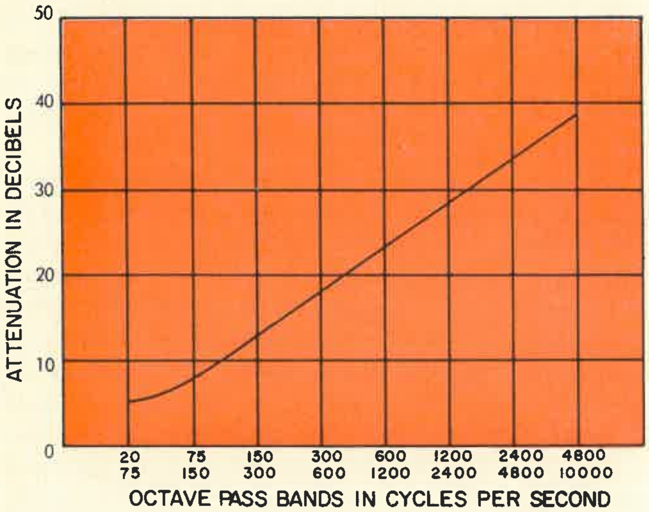

Fig. 9 — Attenuation characteristics for sheet metal ducts, of 22 gauge galvanized steel, passing over room.

Checking the Design

When the system design has been completed for both air conditioning and noise control, it is important to recheck the noise levels in all of the building spaces — whether air conditioned or not. Such a check must include the transmission paths as well as the duct system. Finally, the designs for the cooling tower and intake and exhaust lines to the outside of the building must be examined.

Cooling tower noise levels may be predicted quite accurately. They are, however, hard to control. It is often easier to locate the cooling tower without regard for the most convenient location from a plumbing point of view, in order to obtain the noise reducing effects of screening and distance. The extra cost of piping and pipe friction will seldom equal the cost of providing muffling equipment for the tower. The cost of quieting towers in recent installations has run between 75 and 150 percent of the cost of the tower itself. Since centrifugal and propeller fans of the same capacity have different sound level and directional characteristics, it is sometimes possible to orient a tower equipped with a particular type of fan so that nearby homes or offices are within the quietest area of the noise pattern.

Intake and exhaust openings should be considered during the over-all design of the system. While their tolerable sound output is relative to neighboring background noise and occupancy, every effort should be made to minimize it. Whether it is a school, office building, or factory, the neighborhood annoyance caused by nearby air conditioning systems can create serious difficulty. Once such a problem arises, its solution is more difficult because irritated neighbors generally develop a low level of tolerance. They demand more quieting than would have been needed had the system originally been designed quiet.

The design of quiet air conditioning systems is simple if the engineer follows this procedure:

¶ Determine satisfactory noise levels for all building spaces on the basis of occupancy requirements.

¶ Determine the noise levels produced by machinery and air handling equipment.

¶ Design quieting elements into the system whenever they are required.

¶ Eliminate leakage paths, whether they pass through the walls or holes.

¶ Provide adequate vibration isolation for equipment, piping, and ducts.

¶ Design the cooling tower and intake and exhaust systems to prevent neighborhood noise problems.

¶ Review the noise control design following the completion of the system design.

Noise in the Community...

Consulting Engineer's Responsibility

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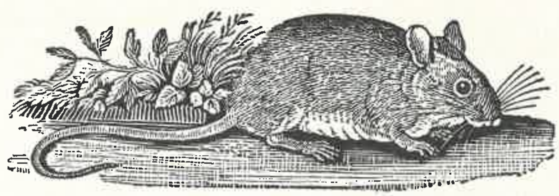

Engineers, particularly consulting engineers, have the responsibility for the plans, designs, and operational characteristics of equipment and facilities for industrial complexes; transportation systems; residential, commercial, and institutional buildings; various utility and municipal plants; and many other types of projects. Most of this equipment and these facilities produce outdoor noise. Therefore, as communities and municipalities grow, so grows the noise level. Problems of excessive outdoor noise in "carefully-engineered" installations have gained more and more attention in recent years.

Initial awareness of elements involving noise each time would have uncovered the problems in the preliminary design stages, thus permitting appropriate action then to change source characteristics, location, or the relationship of source to environment. The consulting engineer has a role in the design or installation in each instance, and may well expect to find himself responsible for the noise and its elimination. Because noise and noise abatement have become an increasingly important part of our lives, measures to control or limit noise have been enacted by various governmental bodies. A series of industrial zoning regulations, municipal statutes, and performance codes have resulted. A number of engineering groups also have devised schemes for predicting the tolerance for various noise sources and noise levels. These schemes set the design objective for the noise level in each particular situation.

The consulting engineer's techniques for judging community response to a new or projected noise source were first formulated in the U. S. Air Force's *Handbook of Acoustic Noise Control, Volume II, Noise and Man*[1], and were discussed at length in the *Handbook of Noise Control*[2]. The technique of evaluation, basically, is a comparison between the particular noise as measured or estimated in various residential areas and a set of hypothetical noises. Adjustments for noise duration, time of year, day or night operation, community background noise, and the noise character will allow the hypothetical noise to be reliably used in estimating community response on a scale ranging from "no complaints" up to "vigorous legal action." Additional conditions that must be considered include the community's socio-political climate, economic factors such as tax rate fluctuations, neighborhood street traffic, and the public acceptance of the noise-source owner and his activities.

Another concern is whether the new noise is or will be louder or noisier than the existing background noises, both day and night. If it is or will be louder, complaints can be expected. If the noise has pure tone components, such as fan blade frequency or compressor whine, it not only cannot be as loud but must be five to ten decibels below the existing background. If the new noise source is twice as loud as the usual nighttime background levels, frequent complaints may occur; when it becomes four times as great, community legal action can be expected. These rough but reliable estimates will give fair warning of trouble if the indicated levels are exceeded.

When the existing background noise level is low, as in many rural and suburban locations, a new sound only two or so times louder than the background will be easily identifiable by its character and the direction from which it comes[3]. Some residents will consider this sufficient cause to initiate a complaint. If the new source is four or more times louder than the background noise, it will become even more objectionable because it will mask many familiar sounds and in many situations may interfere with normal personal activities such as reading, listening to music, resting.

In suburban and urban locations that have fairly high existing background noise levels, the addition of new noises which raise the loudness two to four times can raise the noise conditions from barely tolerable to intolerable. Response to noise is subjective; one community may tolerate a new loud noise without complaint while another may react with lawsuits on the basis of mere audibility of this new noise. The consulting engineer must be aware of all the factors and provide adequate noise control measures if it becomes necessary. Once a problem exists, nothing less than physically moving the noise source may prove satisfactory to the neighbors.

"Quiet" noises can have importance when the noise is so quiet that it can barely be "detected" in the background. This type of noise may not be measurable at the site of the complaints and may be barely audible or possibly fading in and out of human audibility. Barely audible noises, like the drip from a faucet when one tries to sleep, may cause a considerable amount of annoyance. In some instances the auditor *wants* to detect the sound and find a cause for complaint. This can happen in residential areas where an undeveloped industrial site is occupied by a fully conforming plant.

Typical Examples

It would be a simpler task to present some case histories than to outline each class of sources, their problems, and methods of solution. However, our files, like most consultants' files, are confidential. No client wants to admit to its neighbors or future neighbors how bad conditions were or might be. So, the following list describes a few pieces of equipment specified by consultants for installation or required for a particular construction task. Each can be a source of annoyance to the community in which it is used.

¶ *Air conditioning system fans.* These fans make a noise which is predictable for operation in the high-efficiency region of the fan curve. Outside the high-efficiency region, noise increases. Also, overloaded fans may be far more annoying because of the audible result of hunting. Noise levels of intake and discharge air flow should be checked at the nearest neighbor's dwelling. Fans in suburban office buildings, theaters, and shopping centers, as well as in industrial parks, can be day and nighttime noise problems. Quieting fans is readily accomplished with suitable engineered and fabricated or packaged mufflers.

¶ *Cooling towers.* Falling water plus one or more fans are the two sources of cooling tower noise. Careful location of the tower, two-speed operation (low speed after dark), and mufflers all help reduce noise levels. Multiple-cell towers can be operated to minimize noise after dark by running two or more cells at low speed instead of one at high speed. The prevailing theory that a low tip speed prevents noise is a false one. Fans make noise in proportion to their input power, and switching from an axial fan to a centrifugal blower or vice versa may make that particular installation easier to quiet, but not because of tip speed. Also remember that the big annoyance may be water noise. Insist that potential suppliers furnish noise data on future cooling towers for comparison and for the neighbor's comfort.

¶ *Compressors.* Reciprocating, screw, and positive displacement compressors all make noise — a characteristic chugging sound for low-speed units and a whistle or whine for high-speed units. High-speed, multiblade compressors make a sound such as a whine, whistle, or screech. None of these units can have a direct intake or discharge to atmosphere without likelihood of serious complaints from nearby neighbors. Even closed-circuit units, having the noise radiated from the casing or piping, can create high noise levels at large distances. Reduction or elimination of the noise is done by mufflers or by multiple-layer pipe jacketing. Those compressors operating from or discharging to the atmosphere must have special intake or discharge mufflers for the specific compressor and its application, and for the particular background noise.

¶ *Steam discharge lines.* Chemical plants as well as small laundry plants may have steam discharging to the atmosphere from one or more pipes. Often steam ejectors run continuously and the noise is intense even from small pipes, with the sound level increasing with upstream pressure. The character of the noise is determined by the pressure, by the pipe size, and by the pipe shape at discharge. Various commercial pressure reducing mufflers will quiet this noise source.

¶ *Heater and furnace burners.* Chemical plant burners, refinery heaters, and furnaces are relatively noisy, producing a high level of primary intake-air noise. They are capable of producing a single tone or series of tones caused by "organ pipe" resonances within the burner. These tones usually can be eliminated by operating the burners at slightly different points on the operating curve. Small changes in fuel and air-flow settings can make large changes in the level of these tones. The intake-air noise, however, cannot be controlled in this manner. A longitudinally split muffler can be applied as a jacket over the intake if air flow is not affected. New burner settings must be found when the static pressure drop is high.

¶ *Doors, windows, and louvers.* Many modern industrial plants still are being designed with certain doors, windows, or louvers to be open to provide ventilation, process air, or even combustion air for the boiler plant. This is a blatant invitation to receive complaints and possible litigation in industrial areas now being developed outside large cities. Any opening admitting enough air for these purposes will permit sound to radiate nearly as well as if there were no wall acting as a sound barrier. This becomes more evident where there is a direct path from outdoors through the opening to a noisy machine. When a corporation expends time, trouble, effort, and expense in securing a plant location in a new area and seriously attempts to meet local requirements concerning site, smoke, dust, height, and screening, the plant designer and the consulting engineer are shortsighted if they fail to eliminate noise problems before they arise by using forced ventilation through quiet fans and mufflers. Many industries who have based ventilation requirements and noise control procedures on daytime noise conditions have been forced to add expensive noise control procedures on a crash basis for nighttime operations at a later date. These comments do not apply only to noise from punch press operations or sheetmetal working areas; they apply to all types of industrial operation noise from automated materials handling systems and drop forging to lathe and screw machine work. No industrial noise can be ignored safely. For example, paper industry equipment noise can be annoying at great distances from the plant because of the siren-like sounds of the suction roll and the Jordan beaters drifting into quiet homes. In any event, industrial noises heard at high levels during the day or at low, but above background, levels at night can cause serious problems for plant owners and managers. It is the responsibility of the consulting engineer to see that they do not leak out through deliberate openings — or inadvertent openings such as holes in outside walls for installing new equipment covered only with lashed canvas.

¶ *Loading platforms.* Noise from the delivery of raw materials and the loading of products for shipment is the source of some of the bitterest complaints about industrial plants. Four types of noise can occur: truck noise on the local and plant roads; loading or unloading operations; plant noise leaking through open doors during loading; and talking and shouting by truck and plant personnel. Careful location of the loading area, high walls immediately adjacent to the area (if computation shows they will work acoustically), and buffer walls between the interior noise and the loading area will help reduce the annoyance.

¶ *Stack noise.* Many problems are caused by noise radiating from industrial plant stacks, including the noises from sintering furnaces, catalytic regenerators, and boiler plants. Stack noise can come from combustion noise, fan noise, and discharge velocity noise. All three sources can be quieted adequately by careful system design. For system economy, however, it may be more practical to design the system with the noise and then use a stack muffler at the top of the stack. This holds true in oil refineries. Stack dimensions must not permit resonance to occur at the fan or blower frequency. Calculation of the range of wavelengths at the gas temperatures at the appropriate points in the system is necessary. A resonant muffler is not very useful because any change in operating conditions may move the peak noise output to another frequency from that for which the muffler was designed. Short, high-efficiency, straight-through mufflers with enlarged cross section frequently are effective for this application.

¶ *Power plants.* Commercial power plants designed for either large or small distribution systems as well as individual generating systems for a single plant are known noise sources. Noise problems exist in forced-draft systems for the larger commercial coal-burning installations and diesel engines in smaller commercial and private industrial systems. The large commercial systems have been known to generate noise at distances as great as one mile while the smaller systems, often located close to the center of small communities, are a problem for the entire community. The consulting engineer must be sure that the building designed to house the system will not act as an effective radiator of the low frequency blower or engine frequencies. Intakes for fresh air for the blowers may require mufflers for both types of systems. Diesel engine exhaust systems always require an efficient, commercial exhaust muffler. There are many of these systems in use throughout the country, so it is easy to get noise level measurements at a reasonable distance from a unit similar to that planned for a particular application. Beyond that point, though, a check against the background levels at neighboring sites of the new plant, using computed levels for closer or greater distances, will show what noise control measures are needed.

Nothing is Sacred

The endless list includes such items as engine test stands, pipeline pumping stations, school auditorium summer ventilators, bowling alley pinsetting equipment, construction machinery (poorly muffled engines and poorly enclosed engines since about half the noise power is radiated equally from each), industrial plant paging systems, pole and substation transformers, and packaged rooftop refrigeration plants, to name just a few. Only careful analysis of the situation based on measurement or computation of the expected noise level, comparison with the community background, and selection of an appropriate noise control technique either quieting the source or controlling the transmission path can really lead to adequate noise conditions in communities in or around modern commercial buildings and industrial installations. ▲▲

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United Press Photo

To Quiet The Noisy City

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In the past few years there has been much talk about how much noisier our environment has become or will soon become. As so many people, including one judge, have said, "Noise is a by-product of progress." This seems to imply that noise is a necessary by-product of progress. To me, and to many others working in the field of acoustics, this is not so. Many products and systems resulting from man's progress in transportation, industry, the control of the physical environment, and the easing of man's personal workload do generate more noise than the former means of accomplishing the same tasks. But the noise that accompanies the operation need not be inflicted on the surrounding neighborhood, community, state, or nation.

Noise Source Categories

There are four major categories into which sources of noise may be grouped:

¶ Transportation.
¶ Industry.
¶ Heating, ventilating, and air conditioning equipment (the outdoor side).
¶ Man in his day-to-day activity.

In each of these categories are new and old devices and systems that generate more and louder noises. However, for each of the new and louder noise sources there are at hand adequate devices or systems to quiet the source, with possibly one exception – the sonic boom of the supersonic jet transport.

Since man claims to be the beneficiary of this progress, he should be in a position to determine how much noise he is going to allow from a given product or system. But, when an engineer examines a specific situation, he is no longer dealing with man as a biological being; he is dealing with individual personalities or groups of personalities. Some of these men will profit more if they can sell their product or service without quieting it. Other men will not agree that the product or service is satisfactory when accompanied by noise. This is the basis of the conflicts that now exist all over the country, for each of the categories listed.

Transportation affects everyone. Even if people did not fly, aircraft still would be used for the transportation of merchandise, food, mail, and general freight. The same is true of automotive vehicles. The nation's highway system might not be the same if people did not travel by car, but high-speed truckways probably would be with us anyway. The benefits of all of our modern transportation systems are of course indisputable, but cars, trucks, trains, and aircraft are major noise producers. Even weighing the benefit to man, the unsuppressed noise of all three would be intolerable. Therefore it is the responsibility of the engineer, particularly the consulting engineer, to see that airports, aircraft in flight, highways, and railroads do not destroy the physical environment of the communities which they serve or through which they travel.

Several years ago when the bypass jet engine was introduced, it permitted a reduction of noise and an increase in thrust. The balance of these two parameters can be set by the engine operation. The present day operation is to maintain the noise level of the earlier pure jets with their not too effective mufflers and pick up about one-third more thrust. Consider what benefit might accrue to the neighboring community if the noise level were reduced still further and the available thrust only held for emergency use. The argument against this is that it is not economical to do so.

Diesel engines on trucks, buses, and trains can be heard clearly throughout the country almost everywhere including much of the former wilderness areas. Here again, alleged economic reasons have limited the progress of noise control. The apparent problem is that owners — and truck drivers — believe that there is a serious loss of available power when an effective muffler is used on a diesel engine. This is almost myth. The truth is that a well designed muffler-tail pipe system causes very little power loss; an open tail pipe of the wrong length probably can cause more power loss. The real dollar cost is in the initial cost of a good muffler and the possible weight penalty of 100-200 pounds for an excellent, effective muffler. Here again the weight penalty may be more fiction than fact. How many trucks are really carrying their rated load? Many are overloaded unless the police have a weighing station on the route.

Facilities for Maintenance

Buses can be, and have been, designed to be quiet. However, repair of a bus engine requires that the engine compartment be opened. It is well known in the acoustical world that a diesel engine radiates about half of its acoustic output directly from the engine casing. Thus, even with a good muffler, the engine must be located in a well sealed compartment which is cooled by a quiet air handling system. When the engine compartment seals are damaged or the engine compartment door is damaged by other vehicles, the acoustical seals no longer behave as seals. The best muffler in the world will be of no help. Engine noise radiates out through even the smallest leak. Here the consulting engineer can help by including appropriate maintenance stations with suitable repair equipment in his municipal and private truck and bus maintenance facilities. Engineers who work for the bus and truck manufacturers can contribute to the future quiet environment by helping to design engine compartments, access panels, and seals that are realistic in size, shape, and construction so that they will serve as sound isolating systems for the life of the vehicle and not just until the bus goes into the shop for the first time.

Another class of machines, one that bridges the gap between vehicles and industry, is construction machinery. This includes bulldozers, trucks, cranes, backhoes, loaders, scrapers, and compressors. The most notorious of these is the diesel-operated, reciprocating compressor. Here the diesel exhaust and casing radiation combine with the compressor intake to create acoustical havoc near many downtown residential building sites. Again the myth of lost efficiency is used as an excuse for lack of adequate mufflers. If no other code is available, let these contractors provide equipment that meets the Automotive Manufacturers Association 125 sone limit. This is not ideal, but at least everyone in the truck and muffler industry knows how to meet it. It is obvious that if the engineer specifies quiet operating equipment in his construction specifications as part of the general conditions, it is part of the contract, and it can be enforced. This may add a small amount to the cost of the job, but it usually is far less than it costs to have the job shut down by irate neighbors who have gone to court and obtained an injunction.

Even pile driving can be done quietly using the sonic-drive units now available. Where 24-hour operation is anticipated, the extra cost of the special equipment may pay for itself, for more and more cities and towns are writing restrictive laws against noise and construction noise specifically. The consulting engineer can be on top of the situation by specifying quiet operation before his client is required to pay for costly delays and the contractor gets tied up in litigation.

Another problem that transportation and industry have in common is that of site selection. A consulting engineer selects a site for a building, factory, or residential project, or chooses the right-of-way for a highway or airport with great care. The only item usually considered lightly is the relation of the property to the nearest residential neighbors, or conversely, of the new residential buildings to the nearest noise sources. The consultant will survey the site with care, get test borings, study the utilities and sewer routes, and evaluate the drainage. Access for and protection from traffic are both considered. But not noise. Too late, when the buildings are up, when the highway is filled nightly with long lines of trucks, when the new plant is dis-

SICKLES Photo-Reporting

Man makes his own noisy environment through everyday activities. Construction can be one of the worst offenders.

charging pollution-free air noisily into the neighborhood, only then does the one overlooked problem, noise, project its ugly clamor.

Industrial noise, even at great distances, can be audible and disturbing. Today there is little excuse for any industry causing outdoor noise. It is true that this may entail some cost for intake and discharge mufflers on air-handling systems, lagging for pipes connected to them, and discharge mufflers on high pressure steam and compressed air vents used for shutdown of a system, but these are well worth the investment if noise is a nuisance. The client will not necessarily let you know if there is a possible neighborhood noise problem. He may not know himself. Go out and look at the situation and make your own decision. Do it right, and if there are neighbors, make a predicted noise distribution analysis. You usually can obtain from the manufacturers of fans their sound output or you can compute it. Then you can select the suitable noise control system. This also applies to industrial process cooling towers. They can be muffled, but sometimes it pays to resize pumps and piping and relocate the tower on the far side of a building to take advantage of acoustical barrier effects.

Another increasingly sensitive point in many communities is the truck traffic generated by otherwise acceptable local industries. Tying the loading and shipping problem to the noise problem should give your traffic engineer a reasonable chance to solve both. Forget about it, and the community may establish restrictions against night loading activities that will eliminate for them the night truck-noise problem. What will that do for your client?

Everything said about industrial noise applies to noise from heating, ventilating, and air conditioning equipment. One additional problem is that the mechanical equipment noise may penetrate from the exterior into the occupied spaces. Then you can have unhappy people in your own building, and the owner knows just where to point the finger.

Some new problems are showing up now with the more frequent use of total energy systems. No matter what type of drive you pick, you can have trouble in a quiet neighborhood. Reciprocating engines or gas turbines each have a noise that takes special care in muffling. The pulsations of the reciprocating engines can be amplified in poor exhaust piping layouts. Even at considerable distances from the engine, the unmuffled exhaust pulsations can rattle windows and shake the walls of houses. These pulsations may be so low in frequency that conventional noise measuring equipment does not indicate their presence, and earth vibrations are blamed.

The gas turbine drive for a total energy system often is available with a muffler package. However, the manufacturer cannot design for a universal situation, so he should have a background noise survey. Then he can offer the right package for the job. If you give him background noise data and a specified noise limitation on the system as installed, you have a yardstick for acceptance on the basis of noise. The manufacturer may disagree with your specification, but at least he knows that you have one and that he had better be able to meet it.

Not all mufflers of the same size do the same job, and not all manufacturers of mufflers rate them in the same way. Get the guarantee on an insertion loss basis. This says that if the muffler is added to the system built without the muffler, the noise will be reduced according to the table of values submitted. No other specification is as good. A guarantee that the noise level will be less than the tabulated values measured at a specified distance is acceptable, but this has the disadvantage of making it difficult to compare muffler claims from different vendors. Also be sure to check the pressure loss data. Some muffler salesmen forget that the device must pass air or steam at the same time it quiets the noise.

Although there is usually little that the consulting engineer can do about it, man makes noise in his everyday activity. He operates window air conditioners only 20′ from his neighbor's screened porch. One man will listen to his records at full volume while his neighbor attempts to rest. The modern motorized snow shovel and the power operated lawn mower lighten man's work while filling his environment with noise. Some of these noises can be quieted by suitable engine mufflers, but it takes special designs of housing and blade supports to quiet a power mower, since much of the noise is generated by the blades themselves. Different people also seem to have strongly different opinions as to motor boats, motorcycles, and sports cars. The consulting engineer can do little except to help in the formulation of just laws governing the operation of these devices. Bermuda finally set up a statute governing the allowable noise that might be emitted from motor bikes. It now has an enforceable test code and has brought order and quiet out of chaos.

Most that the consulting engineer needs to know about noise has been published in the last few years. There are handbooks, textbooks, and magazines that have published material on noise and its control. Despite our increased knowledge and improved techniques noises are getting noisier and people less tolerant. Noise control is a necessity. We can do something about it and probably will. With the exception of aircraft noise, the future outdoor environment probably will be quieter in most places. An aroused public and alerted public officials are demanding it. There will be a change for the better in the relationship between the airports and their neighbors. There also may be some improvements in aircraft power plants which may make them less noisy. However, it all will take time. The consulting engineer should lead the way. ▲▲

THE BUILDING IS ON A MILITARY INSTALLATION somewhere in the United States. It is a most inhospitable building. It has no windows and only one entrance, heavily guarded. Its administrators obviously don't want the public to know what goes on inside, and perhaps this is kind of them. Inside are nightmares.

In one of the large laboratory rooms, two physicists and a biologist stand about a heavy metal table. They wear thick ear pads. On the table is a dial-covered device about the size and shape of a television set, with a trumpet-like horn protruding from its face. The device is a kind of siren, designed to produce high-frequency sound of outrageous intensity. The scientists are studying the effects of this sound on materials, animals and men. They are wondering if sound can be used as a weapon.

A small delegation of official visitors from Washington shuffles nervously into the room. The visitors are supplied with ear protectors and settled in chairs behind the siren. The physicists turn the device on and tune it in. A colossal high-pitched shriek fills the room. This is the audible component of the generated sound. It is loud enough to hurt the padded ears, but it is only a whisper compared with the main body of the generator's huge yell. The main body is in a higher range of frequencies—higher than the human ear can hear.

One of the physicists begins the demonstration by picking up a wad of steel wool with a tonglike instrument on a long pole. He holds the steel wool in the invisible beam of sound that issues from the horn. The steel wool explodes in a whirling cascade of white-hot sparks.

Next he picks up a flashlight and turns it on. He wants to show what an intense sound field might do to an enemy's delicate electronic gadgetry—the guidance mechanism of a missile, for example. He holds the flashlight in the beam. The light goes out instantly. A fraction of a second later, the glass faceplate shatters.

The biologist has brought a white rat into the room in a small cage. The rat is running around the cage, looking unhappy about all the noise. But his worries don't last long. The biologist lifts the cage into the sound field. The rat stiffens, rises up to the full stretch of his legs, arches his back, opens his mouth wide and falls over. He is dead. An autopsy will reveal that he has died of instant overheating and a massive case of the bends. There are bubbles in his veins and internal organs.

Such is the power of sound. And such is the state of sonics technology in the 1960s.

Sound has been a part of human life and death since prehistoric man used it to track his meals and warn him of danger, and scientists have been interested in it since Pythagoras first tried to figure out the mathematics of musical intervals some 2500 years ago. Yet until the past few years, the science of sound was distinctly low-caste. It had a grubby, hangdog air. Most of the men who pondered it down through the centuries—Francis Bacon, Isaac Newton, Albert Einstein—were men whose main interests lay in other, more glamorous fields. The few men who did concentrate on sound were regarded by most other scientists as unimportant, if not actually nuts.

Nobody gave them any research grants or set them up in expensive laboratories. They had to improvise their own equipment. In the 19th Century and early 20th Century, for instance, three separate teams of French experimenters studied the speed of sound and other phenomena by going underground and sending noises through water pipes and drainage conduits beneath Paris. The miles-long mazes of pipe served the purpose, but the scientists became damp and irritable. A Paris gendarme, hearing strange sounds from a street grating one night, peered into the hole and saw a man squatting below with a lantern and a flute. The man was scientist J. B. Biot, studying some mysteries of musical pitch. "What are you doing down there?" asked the gendarme. "Playing a flute, of course," snapped Biot.

Men like Biot spent much of their time trying to convince the scientific world that they deserved to be listened to. This only made things worse. Professor Dayton Clarence ("Shockwave") Miller, a founding father of the Acoustical Society of America, used to stomp around what is now the Case Institute of Technology in the 1930s with a copy of a 1929 history of science under his arm. "Look at this damned book!" he'd howl, waving it at anybody he could buttonhole. "It has more than five hundred pages, but there are only twelve lines devoted to sound!" His hearers would nod politely. "Gee, Professor," they'd mumble, "that's a shame." Miller later wrote a science-of-sound history himself. It promptly sank from sight in a vast silent sea of indifference—immersed so thoroughly that the New York Public Library's copies, now 30 years old, are still virginally free of thumbprints.

But times change. The science of sound began to get some attention during World War Two with the development of military applications such as sonar (Sound Navigation and Ranging) for tracking enemy vessels at sea. In the 1950s, studies of other sonic phenomena began to disappear one by one behind a shroud of military secrecy—perhaps the most sincere honor that can be granted to any research project. And now, in the 1960s, the science of sonics is distinctly hot. It is glamorous, it is "in" at last. Big old companies such as Westinghouse and Goodrich have established sonics laboratories and are pouring money into them. More money is pouring in from the U. S. Government. New hot-shot sonics companies are springing up on all sides to cash in on the boom. There are acoustics societies and publications and awards and noisy conventions. Suddenly, everybody is fascinated by sound.

A lusty choir of sound-emitting gadgets has arisen to buzz, hoot, whistle and roar in the world's ear. Hospitals use high-frequency sound to clean instruments, dentists to clean teeth, nuclear submarine crews to shiver the rust off tools

THE SONICS BOOM

article By MAX GUNTHER

until recently a neglected stepchild of the technological revolution, the science of sound in exotic frequencies is now cloaked in glamor—and secrecy

PHOTOGRAPH BY J. BARRY O'ROURKE

and scorched food off cooking pots. Athletic trainers use it to massage sore muscles. Surgeons use a more intense variety to detect tumors, remove warts, disintegrate parts of the brain in maladies such as Parkinson's disease. Lower-frequency sound is used as an anesthetic.

Companies big and small have staked their reputations and finances in the sound game. Honeywell and others have invented devices that send out sounds and, by analyzing the returning echoes, give characteristics of objects off which the sounds bounced. Such a device was used in 1965 to find a barge loaded with deadly chlorine gas that had sunk off Baton Rouge, Louisiana, and another will be used this summer by an MIT professor to find two lost ancient cities under the Mediterranean. Smith Kline Instrument Company, of Philadelphia, makes similar gadgets in miniature to detect trouble spots in the human body and to find foreign objects in delicate organs such as the eye. RCA has invented a typewriter that understands spoken sounds and will type anything you say to it. Ling Electronics of California makes a noise generator whose gigantic howl, loud enough to tear electronic equipment apart, is used to test the toughness of space-flight hardware. A New York store, Hammacher Schlemmer, sells a smaller noise generator that is supposed to drown out (with "white sound," a gentle hissing noise) other night sounds and help you sleep. And in case your neighbor's noise generator bothers you, B. F. Goodrich has invented a rubbery material called Deadbeat that stops sound almost completely.

Odd research projects are afoot. The U. S. Department of Agriculture is trying to find out why, in some cases, corn grows taller and cows give more milk when serenaded with music. The U. S. Navy wants to know why ship propellers sometimes sing (a lovely musical tone, but it interferes with sonar); what whales say to each other (they sound like morose cows); and how porpoises under the water and fishing bats over it use sonic echoes to home in unerringly on their prey. Scientists of the Bell Telephone Laboratories tried to discover how we identify an anonymous voice over a phone, and exactly why, and in what ways, music played in New York's Philharmonic Hall sounds different from that in the Mormon Tabernacle (one reason: The Tabernacle's builders used cattle hair to strengthen their wall plaster). The National Aeronautics and Space Administration wants to know what loud rocket noises do to people around a launching pad, and why such noises occasionally cause nausea, fainting and epileptic-like fits. University of Pennsylvania researchers are experimenting with high-frequency sound as a means of shaking slow-penetrating medicines into body tissues. Researchers at the Max Planck Institute in West Germany want to know why workers in noisy places such as iron foundries have more emotional and family problems than those in quieter places. Once-obscure subspecialties such as psychoacoustics (the study of how we hear a sound and what we do about it) and forensic acoustics (dealing with the growing number of noise-nuisance and ear-damage cases taken to court) are growing important enough to begin forming societies and holding conventions of their own.

"It's nice to be needed at last," says New Jersey sonics expert Lewis Goodfriend. He is a dark, wryly humorous man who worked on sonic weaponry during World War Two and now has his own acoustics company, Goodfriend-Ostergaard Associates. The company earns its living by such means as designing quiet offices, determining the effects of noise on aircraft personnel, testing sound-deadening materials and appearing in court as an expert witness in noise-nuisance cases. It is a small outfit but—typical of the times—wealthy enough to afford a complete sound laboratory full of shiny equipment. Says Goodfriend contentedly: "In the last few years this business has gained status. It's hard to explain why, exactly. There haven't been any really revolutionary new discoveries. Most of the work being done today is a continuation or intensification of earlier work, but it sounds new because people never heard of it before and it wasn't *used* before. I can't say what caused this upswing, but I will say I like it."

Sound, the phenomenon that all the noise is about, is a wavelike disturbance in a solid, liquid or gas. The disturbance travels at about 1090 feet a second in air at sea level, roughly five times as fast in water and 15 times as fast in iron. It is unfortunate that we do most of our hearing in air, for air is one of the poorest conductors of sound. A detonated 50-pound dynamite charge can be heard for maybe ten miles in still air, but for more than 10,000 miles in water—which is why the U. S. Navy is hopefully developing equipment for hearing enemy vessels hundreds of miles away.

Sounds have two main characteristics: frequency and intensity. The frequency is the number of waves (usually called cycles) that pass a given point in a given time. The human ear and brain detect frequency as pitch—how "high" or "low" the sound is. An average young man can hear tones from about 15 cycles per second to 20,000 cps; but as he grows older, his upper threshold drops, and he may end his life virtually deaf to tones higher than 10,000 cps. Luckily for him, most music lies within that range. The lowest note of an organ (made by a pipe 32 feet long) is about 16 cps. The lowest A on a piano is 27½ cps; the lowest note a basso can sing is about 80. A soprano can reach as high as 1200 cps; a piccolo, 4186; an organ (with a pipe less than an inch long), 8372.

Sensitivity to pitch differs from person to person. There are various degrees of "tone deafness," the inability to hear fine differences in frequency. At the other end of the scale are people such as piano tuners, who can hear the difference between an A tuned at 440 cps (the international standard) and 441 or 442 cps (which some orchestras prefer). Still more rare are the 25 people in a million with "absolute pitch," the ability to sound a perfect 400-cycle A or any other note from memory. "I've never thought about it much," says one man who has this rare knack, Connecticut musicologist-composer-organist-choirmaster Dr. Robert Rowe. "I remember a note the way I remember your name. It's there when I want it, that's all."

Nobody knows why people's pitch sensitivity differs or where the gift of absolute pitch comes from. Some say it results simply from an unusually loud and steady ringing in the ears. You probably found this ringing especially loud the last time you had a fever. It's thought to be caused by miniature vibrations of ear parts. The interesting thing about it is that, in any one individual, it's usually about the same pitch. If you want to fake absolute pitch, you may be able to do it by using this ringing as your reference point.

Frequencies higher than the human hearing threshold are called ultrasonic. Dogs, bats, porpoises and other creatures can hear higher frequencies than humans—in some cases as high as 150,000 cps. "But this doesn't make them anything special," says an engineer of the Hewlett-Packard Company, which makes ultrasonic listening devices for detecting leaks in boilers and other pressure systems. "Hell, with a little ingenuity, a man can hear any frequency he likes." At the University of California, in fact, physicist Klaus Dransfeld has produced and recorded frequencies in the fantastic neighborhood of 20 billion cps. High frequencies like that are usually produced with piezoelectric crystals such as quartz, which change shape in an electric field. They can be made to hum ultrasonically by applying a rapidly alternating field.

The other main characteristic of a sound, its intensity or "loudness," is most often measured in decibels—which is unfortunate, for decibels are hard to talk about. The decibel scale is a logarithmic scale, not a scale of equal-sized units like inches or pounds. Every upward step of ten decibels represents a tenfold multiplication of sound energy.

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Thus, a sound of 50 db is ten times as powerful as one of 40 db, and one of 100 db is a million times as powerful.

When acoustics professors are trying to wake up sleepy students, they like to say that the softest sound the human ear can hear is that of a baby mouse urinating on a dry blotter three feet away—roughly one decibel. Modern supersensitive microphones made by Bell Telephone, General Radio and others can hear much softer sounds. They can clearly pick up, for example, the noise made by a Kleenex fluttering down and hitting a solid concrete floor 50 feet away. A spy on the sidewalk outside a ten-story building can hold such a microphone against the wall and—if it's nighttime and there are no loud noises in the building—hear a conversation being held on the top floor.

But most human hearing experiences come from much louder sounds. Dry leaves rustling in a breeze produce about 10 db; ordinary conversation, 60; a full-volume *discothèque*, about 80. The *discothèque* volume is about the loudest that the ear can take for a long time without discomfort. The loudest sounds we're normally subjected to are about 10,000 times more intense, up in the range of 120 to 130 db. This is the range where sound begins to cause physical pain and deafness. Sounds like these are manufactured by such companies as the Leslie Company, the nation's biggest maker of foghorns and ship whistles; and Federal Sign and Signal Corporation, the biggest maker of sirens. The Queen Mary's whistle, says Leslie, produces 123½ db at a distance of 100 feet (the standard distance for measuring such noisemakers). A big-city air-raid siren clobbers the ears with 125 db. A large Coast Guard foghorn has about twice that power: 128 db.

A sound that big can cause temporary or permanent deafness, depending on its duration and frequency (the ear is most sensitive to sounds in the middle and upper range of a piano). It can also cause other odd effects, such as blurred vision from oscillation of the eyeballs.

Louder sounds cause still odder effects. A decade and a half ago, a scientific group at Pennsylvania State College made a shriek so colossal that it could brew coffee, smash insects and kill mice. "On looking back, I find the whole set of experiments kind of macabre," says the chief noisemaker, physics professor Isadore Rudnick, now at UCLA. "We were developing intense sound sources. At that time, almost nothing was known about the effects of intense sound on humans. Occasionally we'd remind ourselves of the early days of radioactivity, when researchers unknowingly exposed themselves to crippling doses, and we worried."

To find out what a big sound might do to people, besides deafening them, Professor Rudnick and his colleagues built the most powerful siren ever conceived to that date. It made what was, as far as anybody knew, the loudest continuous sound ever heard on earth up to that time: 175 db, some 10,000 times as strong as the ear-splitting din of a large pneumatic riveter. The frequency range of this enormous howl was from about 3000 cycles per second (near the top range of a piano) to 34,000 cps, in the ultrasonic range.

Strange things happened in this nightmarish sound field. If a man put his hand directly in the beam of sound, he got a painful burn between the fingers. When the siren was aimed upward, ¾-inch marbles would float lazily about it at certain points in the harmonic field, held up and in by the outrageous acoustic pressure. By varying the harmonic structure of the field, Professor Rudnick could make pennies dance on a silk screen with chorus-line precision. He could even make one penny rise slowly to a vertical position while balancing another penny on its edge. A cotton wad held in the field would burst into flame in about six seconds. "To satisfy a skeptical colleague," reports Professor Rudnick, "we lit his pipe by exposing the open end of the bowl to the field."

The researchers were careful to keep themselves out of the ghastly sound beam, and they wore ear plugs and pads. All the same, they were troubled by odd physical effects while working next to the beam. They were plagued by dizziness and blurred vision. Fatigue set in quickly. There were tickling and "sizzling" sensations in mouths and noses, sometimes acutely disagreeable.

Working with the group was Dr. H. Frings, a zoologist interested in pest control. He discovered that a mouse exposed to the colossal sound died in about a minute, mainly of internal

"She's truly a callgirl's callgirl."

overheating. Insects were virtually disintegrated in ten seconds. According to the research team's report, a typical mosquito suffered the following catalog of misfortunes: "Both wings completely shattered. Abdomen full of bubbles. Body badly battered. Scales gone. Antennae in very bad shape . . ."

A scream like that is a potential military weapon, and since the mid-1950s, such supernoisemakers have been muffled in secrecy. "There's no question that a loud sound can do damage, or at least could be used to disorient enemy troops or flush them out of a hiding place," said an Army officer one night recently in Washington, gazing pensively into a martini. "The question is, would such a weapon be practical? It takes a lot of power to generate a damaging sound. Bullets are a lot cheaper, you know."

Still, superscreams are now being generated in military labs. Robert Gilchrist, president of Federal Sign and Signal, tells of tantalizing rumors that have circulated in the noisemaking business over the past few years. "We just heard about a siren of some kind, supposedly intended for Vietnam," he says. "It's said to produce something like 200 decibels." That would be several hundred times as powerful as Professor Rudnick's monstrous screamer.

Gilchrist is a quiet man who escapes from his loud business by eating in quiet restaurants. Setting down his coffee cup with care so as not to make it clang on the saucer, he starts to tell of cases in which his company's small civilian sirens have been used as weapons. "There was a case in Illinois a few months ago," he recalls. "A race riot. The local police broke it up by simply driving their cars into the mob with the sirens going. A sound like that is like a bucket of cold water in the face: It breaks a man's train of thought. The rioters couldn't pay attention to what they were doing. They stopped fighting and just milled around. The police got the two gangs separated and drove them in opposite directions with the sirens—actually pushed them down the street with sound."

The subject of sonic weapons is a touchy one. If you ask questions on a sober morning in the Pentagon, you receive dry chuckles in reply. "Sonic weapons? Haw, haw. You've been reading too much science fiction, pal!" But questions asked of big organizations such as MIT, the Bell Telephone Labs and RCA reveal the oddly contradictory information that all have Government sonics contracts that they aren't allowed to talk about. Some of these contracts have to do with well-known military applications of sound such as sonar and other echo-ranging systems. Other sonics research is more bizarre.

The Nazis in World War Two were interested in the military promise of sound, though they were never able to use it effectively. Early in the War, they experimented with attachments that would make bombs and artillery shells scream, moan and warble. The hope was that these loud sounds would make troops and city populations panic. It didn't work, except on small children. Toward the end of the War, as the Reich ran out of ammunition, reports circulated that German bombers were dropping beer bottles. The bottles made a high-pitched shriek as they fell, the reports said, and were obviously intended as a scare weapon. Two American scientists, Harold Burris-Meyer and Virgil Mallory, investigated the rumor. Mallory stood on the shore of a small lake in New Jersey one afternoon, and Burris-Meyer flew over in a plane and dropped bottles of assorted sizes and shapes into the lake. "I heard no sound that was remotely frightening," reported Mallory. "In fact, it was quite a pleasant musical afternoon."

Near Dachau, site of the notorious concentration camp, a team of Nazi scientists experimented with the use of powerful sirens to control groups of people. The hope was that, if a sound could be made loud enough, it could be used to disorient or paralyze enemy troops in certain battlefield situations. There may have been more sadism than science in these experiments, for the only known results were that several Jews used as test subjects were deafened.

Research since then has been more useful. At an Air Force medical lab in Ohio, for instance, a group led by Dr. Henning F. von Gierke has been making similar studies of the effects of sound on man. Dr. von Gierke's main concern is with the unwanted effects of loud aircraft noises and other 20th Century sounds on the Air Force's own men, but military planners have watched this and related studies with an eye on weapons possibilities.

One rather weird finding to come from such research is that various parts of the human body resonate to certain frequencies of sound. (A resonance is an answering vibration: Hold a banjo near a piano and play an A on the piano, and the banjo's A string will sing.) Some body resonances are mildly uncomfortable. Some are worse.

In New York recently, an acoustics engineer demonstrated one such resonance to a group of Columbia University students. He sat them in a room and bombarded them with massive sound at a frequency of about 75 vibrations or cycles per second—roughly the pitch of the next-to-lowest D on a piano. Within seconds, half the men were hurrying out of the room. Seventy-seven is the frequency at which the average human anal sphincter resonates. When it resonates hard enough, it can no longer be controlled.

Such a sound could conceivably be used to demoralize enemy troops—or, more likely, to cool off mobs and quell riots. It would be a weapon with a sense of humor—certainly with a bigger smile than other police crowd-control weapons, such as cattle prods, night sticks, fire hoses and tear gas. "Any such weapon will have to wait for another step forward in sound-making technology before it's practical," says Lewis Goodfriend. "At present it's too expensive to make big sounds." All the same, at least one siren-making company is now reportedly experimenting with a huge low-frequency boomer for crowd control.

Other body resonances have other effects. A New York journalist, George Riemer, recalls a pilgrimage he made to the Newport Jazz Festival in Rhode Island some years ago. At one late-night party, among other interesting sights, he saw a girl lying ear-down on the floor next to an enormous bass fiddle. The bass man was playing, watching the girl with interest. Riemer squatted down to find out what was going on. "Aren't you afraid you'll get stepped on?" he asked the girl.

She looked up at him dreamily. "That's the chance I take," she said. "It turns me on. I get it through the floor. I mean, it turns me *on*!" A year later, Riemer heard that she had married the bass man.

There is much that still has to be learned about sound and the human response to it. Another odd effect, not at all clearly understood, is that a loud sound can drown out other body sensations, such as pain. A dentist in Cambridge, Massachusetts, a big, genial man named Dr. Wallace Gardner, chanced on a way to use this effect in 1958. He had a patient named Joseph C. R. Licklider, a psychologist from the acoustics firm of Bolt, Beranek and Newman. Licklider didn't like the sound of a dental drill, and he theorized that patients might be happier in the chair if they couldn't hear that menacing whine. Together, Gardner and Licklider developed gadgetry for masking the sound. The cringing patient put on a pair of earphones. By turning knobs in a control box on his lap, he could hear either tape-recorded music or white sound. He could turn the sound up to thundering volume if he liked.

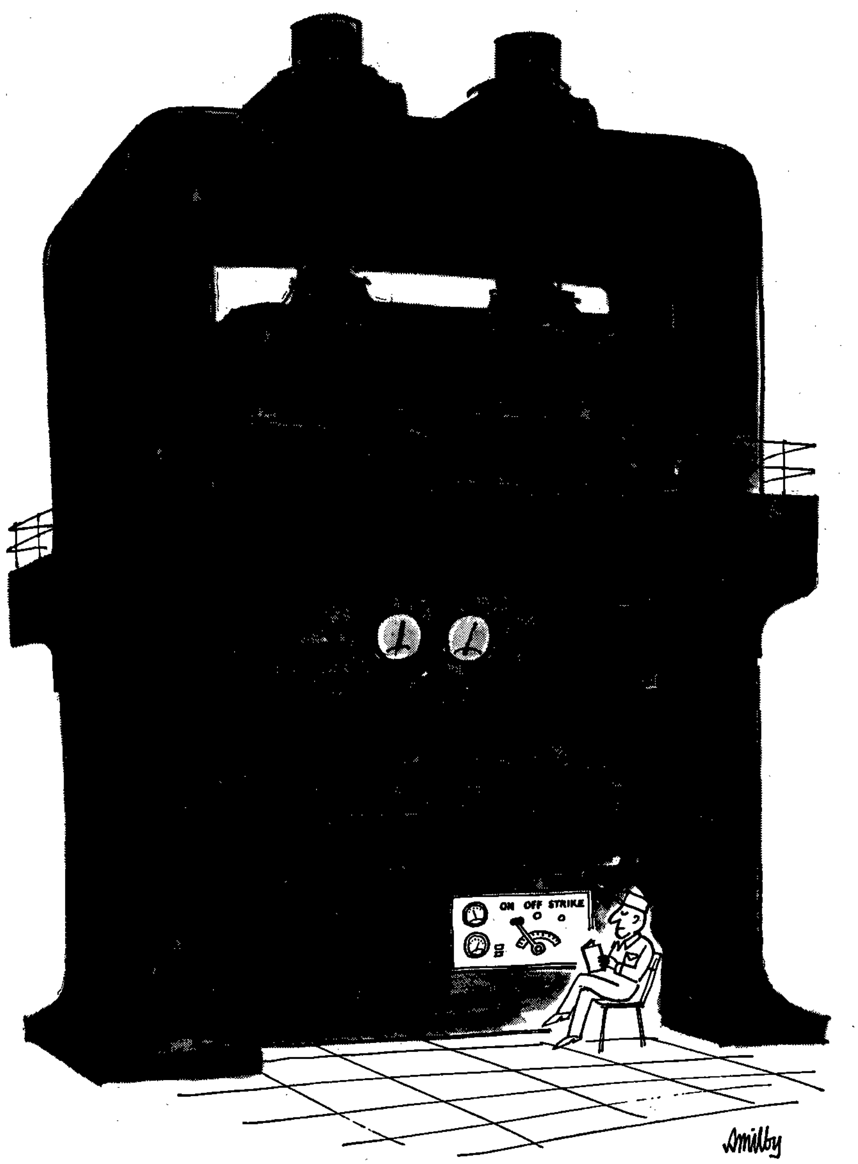
First Licklider and then other patients tried the idea. To Dr. Gardner's surprise, they reported that they not only couldn't hear the drill, they couldn't feel it, either. Somehow the sound masked the pain. A year later, Dr. Gardner for the first time pulled a man's tooth with no anesthetic other than sound. The man listened to white noise and a Beethoven symphony and reported feeling perfectly comfortable during the operation. Today, dentists throughout the country use this "audio-analgesia." It doesn't work with everybody, but it works so well with some that dentists have used it to pull entire mouthfuls of teeth without hearing a word of complaint.

Why does it work? Nobody knows. Dr. Gardner's theory, supported by some psychologists, is that there is a limit to the human brain's sensation-receiving capacity. If the brain is receiving a huge amount of sound, it may have little capacity left to receive pain sensations.

Sound may also leave the brain little capacity to think. This is why a siren can break up a riot—and it is also why people who live or work in cities, or in industrial plants or near airports, are making more and more noise about the noise. "The more technology advances," says Frederick Van Veen of General Radio Company, which makes sound-measuring instruments, "the noisier it gets. And the noisier it gets, the harder it is on people who work with their brains."

Van Veen took one of his company's noise-level meters to Manhattan one day recently. He wanted to know the extent to which city noise in the mid-1960s interferes with conversation, and he had his meter set to pay special attention to frequencies of sound that interfere most with talk. With this setting, any sound clocked at 70 db or more is one that will require some degree of shouting or will drown out words entirely. On a sidewalk at the corner of 47th Street and Second Avenue, Van Veen got readings of 70 to 74 db. This was at 2:30, a relatively quiet time of afternoon. In a bus going through a tunnel, he clocked 75 db. On a subway platform, ten feet from a passing train, he read 90 db.

Citizens of New York and other big cities don't really need decibel readings



to tell them noise levels have been rising. One summer morning last year, an angry Manhattanite, tormented beyond endurance by the vast cacophony of his city, rose from his bed, ran outdoors and jammed a noisy Sanitation Department man head-downward in a garbage can. "I'll make this goddamn city whisper!" he roared. "All right, all right," said the mournful voice in the can, "quit shouting."

Cities have always been noisy. The Greeks of ancient Sybaris arrested people for shouting in the streets. The Romans told dirty jokes about the Sybarites' sensitive ears, holding that Rome's noise was proof of its virility; but Juvenal, Cicero and other thinking Romans had to flee to the country to get any work done. In later times, Marcel Proust paneled his study with cork to shut out the "terrible voice" of Paris. Charles Babbage, 19th Century English mathematician who fathered the modern digital computer, made himself notorious with incessant complaints about the noise of London. Bands of street musicians would come miles out of their way to play gleefully beneath his window. He and his ladyfriend, the Countess of Lovelace, a daughter of Lord Byron, pelted the musicians with rotten fruit and meat bones. "God, oh God, why did you give me ears?" Babbage would howl.

If things were bad then, they're nearly intolerable now. It's estimated that the average noise level of the average city has increased by about one decibel per year for the past 30 years. This has caused all kinds of problems. Constant noise damages the hearing. It robs people of sleep. It makes them irritable. The World Health Organization in 1966 warned that "noise pollution" is one of the worst health hazards in cities all around the globe. Some psychiatrists have even suggested that the past decades' increases in violent crimes, common to cities of all industrial nations, may have resulted at least partly from too much noise. "Even such a thing as interrupted sleep may be dangerous," a psychiatrist told a New York mental-hygiene committee in 1966. "If people are prevented from dreaming, severe psychotic symptoms may appear." Noise, in short, drives people nuts.

The need for at least occasional quiet seems to be universal among animals. Some years ago, two psychologists rigged up an experiment to show that man is not the only creature with an altruistic love for his fellow creatures. They hung a rat by his tail. He squealed. Other rats in the cage could lower him to the floor by pushing a release lever, and after a little practice, they learned to do this as soon as they heard their buddy squealing. "Aha, altruism!" said the psychologists. A year later, two other psychologists at the Defence Research Medical Laboratories in Toronto duplicated the experiment. But instead of hanging a rat by the tail, they used recordings of white noise. The rats learned to push a lever and stop the noise even more quickly. Conclusion: altruism, shmaltruism. The rats just couldn't stand the damned noise.

B. F. Goodrich, maker of Deadbeat, has recently been publicizing a guess that noise costs the nation's industries $2,000,000 a day in decreased human efficiency and in compensation for injuries (not only damage to the ear but also injuries resulting from not hearing a danger signal or warning shout). Things are bound to get worse before they get better. California and a few other states, New York and a few other cities, have recently passed noise-limiting laws, but these are only now in the stage of being tested in court. While the tests go on, technology will get noisier. In about two years, to mention only one example, supersonic jet airliners will probably be flying over our already noisy towns and cities. A plane flying faster than sound (660 mph at an altitude of 35,000 feet) causes a sonic boom, a shock wave that is sometimes loud enough to break windows. Sonics experts have spent years trying to find a way to eliminate this jarring noise, but they're no closer to a solution than when the first booms were heard in the United States in the early 1950s.

"There's a lot to be done in this business," Lewis Goodfriend told a reporter recently, as they strolled down a sidewalk on the way to lunch. "There are two big avenues of research: learning how to use sound and learning how to get away from it when it isn't wanted. Actually, I think we're just on the threshold of——"

But it was 12 o'clock, and a noon whistle began to screech from a building nearby, and the rest of Goodfriend's words were lost in the din.

"But what if he isn't Clark Kent—?!"

Acoustical Engineers Cope with a Noisier World

Lewis S. Goodfriend, P.E.

The interaction of new technology in acoustics and the continuing need for regulation and control of noise in the workplace, in dwellings, and in the out-of-doors environment has increased the need for competent acoustical engineers. It also has radically changed the way acoustical engineering is applied, leading to new developments in:

- Instrumentation that uses state-of-the-art microprocessor technology.
- Methods for modeling noise sources and predicting noise levels from complex noise sources.
- Methods for evaluating noise impact.

Accompanying developments in technology is the publication of a wide range of textbooks and handbooks covering a variety of aspects in the field of acoustical engineering.

In applying this technology to engineering problems, the 1980s has seen and will continue to see the growth of large environmental and transportation engineering firms. Personnel in these firms are trained to do field surveys and computer modeling of environmental and transportation noise sources, but often are not trained in the physics of acoustics, the technology of noise control, or the design and limitations of instrument systems. To provide innovative acoustical engineering solutions is the job of the highly skilled practitioner, the consulting acoustical engineer.

Among problems he faces are many familiar ones that today are becoming more severe. Examples include:

- Locating higher energy devices that are closer to dwellings, offices, and hospitals without creating a noise problem.

Mr. Goodfriend heads the acoustical engineering firm of Lewis S. Goodfriend & Associates, Cedar Knolls, New Jersey.

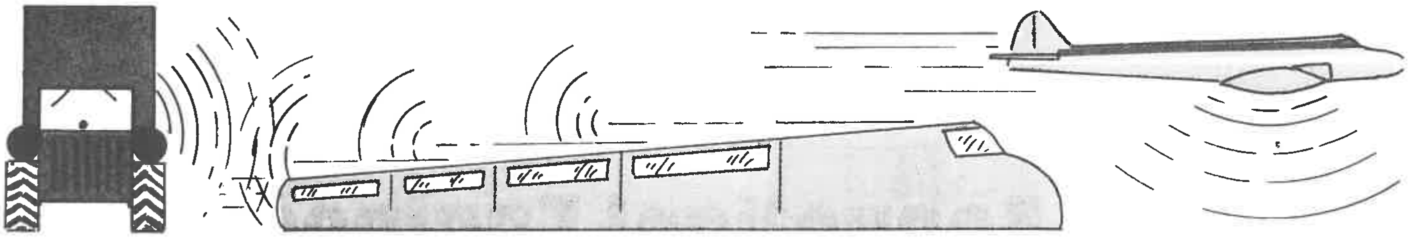
- Designing structures that will be free of noise caused by adjacent transportation systems and terminals.
- Providing noise control for buildings using new types of HVAC systems.
- Providing quiet office environments where high energy, high speed, and high noise-level machines are used.
- Developing noise control concepts for designers of new and improved consumer products, office equipment, and manufacturing machinery.
- Designing sound reinforcement and communications systems using new analog and digital hardware.
- Assessing multiply impacted environments from acoustical and other sensory aspects.

Mechanical Equipment

Modern buildings and plants have a number of mechanical items that require evaluation. These now include emergency generators and uninterruptible power sources and cooling towers and air-cooled condensers.

Each unit should be modeled and its effect added to the total effect at the noise measuring location. Although one exhaust fan, one turbine hall, one rooftop ventilator, or one process plant pump may generate only 20 decibels at the test location, 20 units may put the noise level beyond the desired range. This means that every fan, blower, pump, and machine must be identified, and its contribution to the total noise computed, usually for each side of the site.

Once the decision has been made to provide noise control, the problem becomes one of choice. Although noise control usually brings to mind mufflers and enclosures, there are other useful methods of control, including changing speeds, moving exterior noise sources to take advantage of distance and natural and man-made barriers, vibration isolation, and the rotation of sources to take advantage of radiation patterns. Changing models and modifying the machine housing also are op-

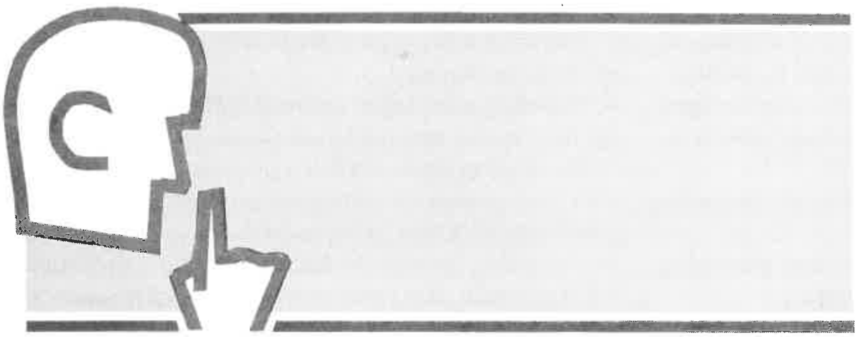


tions, the former at the time of purchase, the latter after the problem develops.

Documentation of source noise-level data abounds for air handling equipment, cooling towers, and power plant equipment. Less is available for pumps and boilers but reasonably good mathematical models are available for fans and blowers in the ASHRAE *Handbook*.

Isolating Buildings

Current land use concepts place hotels, office buildings, warehouses, and industrial parks close to airports and the rights of way of highways and rail transit systems. In some instances, rights over roads and rails are used for dwellings, offices, and shopping malls, establishing the need for isolation from both noise and vibration.



The isolation of a building from rail or highway noise conventionally is accomplished by improving the building skin: walls, windows, and roof. In most cases computer models of wall sections can help, e.g., in some cases demonstrating that expensive double glazed window systems will perform better acoustically than the curtain wall in which they are used. For windows, those with widely spaced lights and a perimeter acoustical absorbant are the most effective, whereas conventional thermal windows perform poorly at low frequencies.

In any building where isolation from out-of-doors noise is critical, sealing leaks around windows may be as important as the window itself. Improvements in frame design and installation procedures have helped, but in most cases the use of sealants between the window frame and wall still may improve isolation.

Interior HVAC Noise

Control of valve/mixing box noise, slot diffuser velocity noise, and variations of VAV system noise does not require the use of exotic technology. In most instances, the data on device noise are available from the manufacturer. The room levels, then, can be computed and appropriate controls used, if necessary. Open plan offices, too, usually pose little problems except in areas where additional local masking is required to maintain privacy.

Business Equipment Noise

The use of high technology devices, such as computers, printers, and copiers, creates a noise problem in many modern offices. Although the manufacturers of this equipment are developing quieter systems, present systems may be in excess of comfortable levels. Some enclosures are available for printers, but, generally, the following acoustical controls can offer considerable improvements:

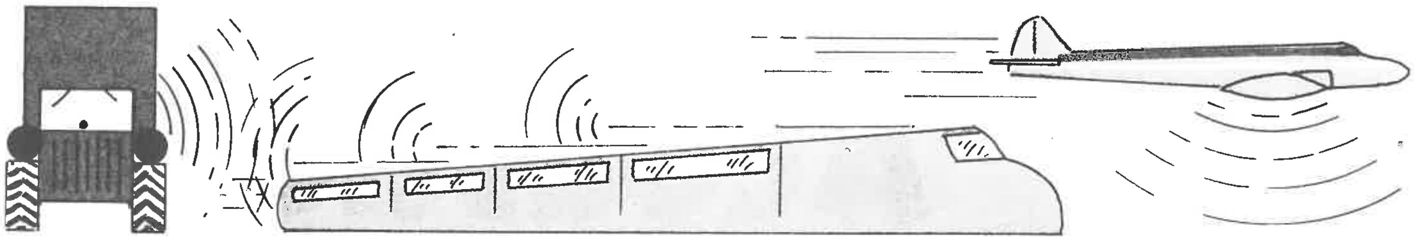
- Adding panel damping, acoustical seals, and interior sound absorption to existing enclosures.
- Adding external mufflers designed to yield modest noise reductions while not appreciably increasing the static pressure.
- Using sound absorbing wall panels or freestanding barriers that have sound absorbing faces to absorb equipment noise.
- Purchasing sound control cabinets for equipment.

Measured noise levels may drop only a few decibels as a result of the above noise control measures. But the change in sound, usually seen as a reduction in the high frequency components, reduces the annoying portion of the noise spectrum.

Sound Systems

Advances in both loudspeaker design and in analog and digital electronics have provided considerable sophistication in sound system design. The cost of such sophistication, however, is a penalty that may raise the price by a factor of three or four. And faced with providing a marginally effective system or walking away from a job, most engineers ignore the latter. Still, there is no reason for any assembly hall to have problems with coverage or quality unless the architectural designer and sound system designer cannot locate the equipment suitably, considering the available options.

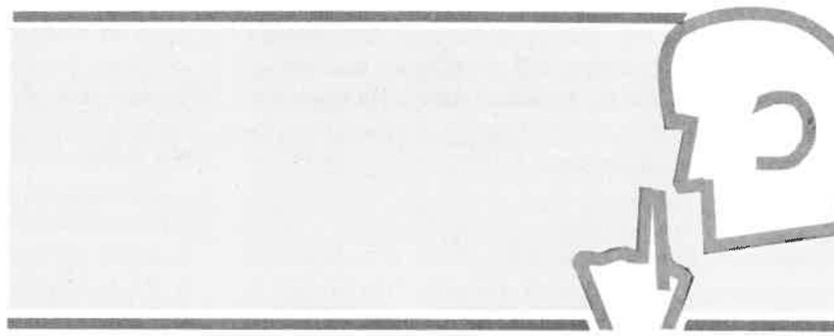
Combining console capability with studio acoustics allows the artist the wide range of flexibility he demands today. The design of consoles for major halls is split be-



tween acoustical and sound system engineers and manufacturers. There are so many options available that the real problem now facing engineers is to define the client's needs and then to integrate them into a realizable configuration.

In terms of studio acoustics, the concept has come full circle with some producers and artists working in dead spaces with microphones everywhere, then mixing the components at the console. Still popular, however, are live-end dead-end studio acoustics and studios with few microphones at relatively live locations, an arrangement that evolved in the early postwar period.

Environmental Assessment



As indicated earlier, advances in instrumentation have enabled the collection of environmental noise data. The technique is to leave remote measurement units on site for one or more days, noting the data and resetting the equipment daily. While data of this genre do not tell what the sources were, it gives many of the statistics needed by engineers. In critical situations, an observer should be at the site, annotating the data. Then, and only then, does one really know what is happening. This method costs more, but what good is low cost bad data?

Multiply impacted environments also create assessment problems. For example, noise always appears louder to communities that also are exposed to particulates, odors, and traffic. And in dwellings, the same noise may seem louder at night because many other noises have abated. In both instances, the acoustical engineer must evaluate the alleged noise problem by comparing it to a community relatively free of the other sources. A decision then can be made as to whether the noise contributes to community annoyance. Note, too, that codes vary from town to town and state to state. They may be stated as single numbers or be spelled out by octaves and include limits for impulsive noise and tones. This makes every assessment and every design a challenge. The design that worked in one place cannot be used to solve an identical problem in another location.

Back to Basics

Still, the approach to solving noise problems remains essentially the same, finding the answer to a few basic questions: how much noise does the equipment make, what is the desired noise level, and what type of noise control, if any, is required? The procedures involved — although a bit more complex than implied — must be followed if design goals are to be achieved.

The assessment and control of equipment noise for almost any project will follow the same general rules. Shortcuts are not allowed. The rules:

- Answer the question: Why are we doing this noise study?
- The answer should yield the noise goals (or criteria) to be achieved.
- Identify where and when the goals are to be met: property line, zone boundary, or nearest neighbor, and at what hours they apply.
- Measure the ambient conditions at each boundary or other critical points, noting unusual occurrences during the period.
- Obtain source noise levels for all of the equipment to be studied, using manufacturers' data, mathematical models, scaled source data from field tests or similar units, and published articles.
- Scale the noise levels of each source to the various specified locations and make tables of octave band levels, adding them on an energy basis.
- Compare the expected noise levels with the design goals and note whether any sources contribute the major portion of the sound energy at each location.
- If needed, develop noise control measures and repeat the previous two steps.
- Allow some margin for error in the predictive methods. This is difficult, but a knowledge of the predictive methods and scaling techniques provides some basis for estimating the potential error.
- Make a table of noise control measures required to meet the design goals. ΔΔ