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AMENITY AND THE FUTURE OF DESIGN IN ACOUSTICS

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Sound and light are our two most sophisticated and subtle media of communication. The acoustic environment is largely public — sound is widely propagated and affects many people — while the visual environment is more easily controlled. The problem of design in acoustics is thus twofold — to protect the individual from unwanted sound, and to allow at the same time the greatest possible freedom to listen and to create new sounds. While passive noise control is effective in many cases, there are many future opportunities for the application of active noise control techniques to produce a satisfactory collective, or personal, acoustic environment. When a personal acoustic space has been achieve, there are then opportunities to decorate that space with sound — either natural sound or sound specially shythesised for the purpose — and to connect it to the acoustic spaces of other people. The ways in which these objectives can be achieved using present techniques, and the new ways in which they might be achieved in the future, are discussed, with particular reference to music, speech and noise.

1. INTRODUCTION

In terms of amenity, in the Japanese sense, the field of acoustics should be close to the centre of our concern, for the acoustic environment is in many ways a public rather than a private one — we cannot close our ears, and even solid walls have only a limited effect on the intrusion of sound. Of course the public nature of the acoustic environment has positive aspects as well — orchestras and choirs pool their individual acoustic resources, and large audiences can gather to hear their concerts.

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For true amenity in design we need to be able to isolate, at will, our personal acoustic environment from that imposed upon us from outside, and then to decorate it acoustically to our taste without intruding upon the environments of others. One of the low points in design amenity in this area is the portable high-fi audio system, or "ghetto blaster" as it is sometimes known. The technical achievement may be admirable, but the destruction of public amenity that often occurs is lamentable. At the other end of the scale comes the Walkman cassette player, which provides a chosen acoustic environment for the wearer while having no influence on the amenity of the environment.

In this brief survey I would like to consider some of the problems, some of the solutions, and some of the exciting prospects ahead in this field.

2. THE PUBLIC ENVIRONMENT

Individuals may sometimes wish to participate in a communal acoustic environment, but more often the wish is to isolate our individual environment, so that we may enjoy quiet or else create our won individual acoustic. It is an important part of environmental design amenity to allow this to be achieved in the most effective and economical way possible.

Machines, regarded as noise generators, are powerful and intrusive, and much of their noise output spans the range to which our ears are sensitive. Sometimes the acoustic output is a desirable feature of the machine, as in musical instruments or sound systems, but often it is an undesired by-product which we should seek to minimise. Among the chief offenders are heavy transport, such as railways, automobiles and aircraft, and the acoustic environments that they influence are both the internal compartments occupied by passengers and the external landscape through which they pass.

The most economical and effective procedure is to reduce the noise at its source, either by redesign of the machine or isolating it with heavy enclosure, as in Fig.1(b). If this is impossible or of limited effect, we can isolate the more sensitive listening environment by an appropriate screening enclosure as in Fig.1(c). As a last resort, the ears of individual listeners can be acoustically isolated, as in Fig.1(d). There are limits to the noise reduction than can be achieved by redesign, for noise-reduction measures tend to reduce machine efficiency. Even well designed machines may radiate as acoustic noise somewhere between 1 part in 100,000 of their operating power, for an electric motor, and 1 part 1000 for an aircraft jet engine. For comparison,

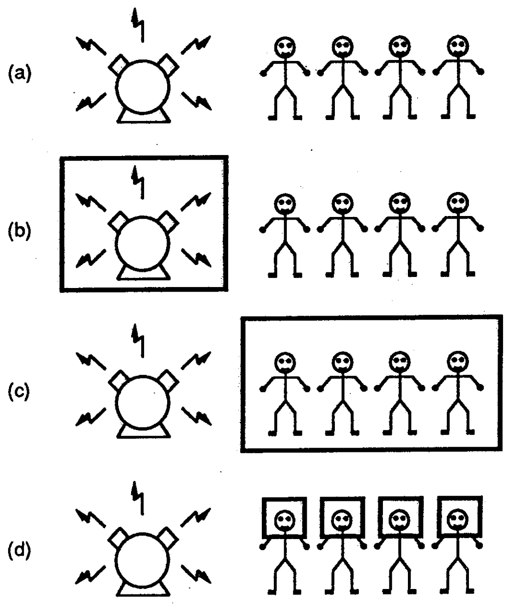


Fig.1 (a) The problem of noise; (b) the ideal solution — contain the noise; (c) another solution — protect the listening environment; (d) the ultimate solution — protect individuals even a loudspeaker is typically only 1 percent efficient in converting electrical to acoustic power! A large jet aircraft may thus radiate up to a kilowatt of acoustic power, and such a wideband noise is audible at a distance of up to 20 km in otherwise quiet conditions. A sound-reducing enclosure is out of the question for aircraft, and even for road vehicles much of the noise is generated by wheel contact and other mechanisms that are very difficult to enclose. Noise barriers can reduce the impact of road traffic noise on the environment to some extent, but the complete solution of placing roadways entirely underground is prohibitively expensive, as well as creating other problems. It therefore becomes necessary to consider placing sound barriers around individual acoustic environments, in addition to noise reduction procedures a the source.

Heavy building construction with sealed double-glazed windows can give good protection to people living in noisy environments, by only at the expense of added construction costs and the need to maintain air-conditioning. Light-weight architecture is much less efficient in providing isolation, but some measure of relief from the higher frequencies can be obtained by the use of solid high walls around the building site. Traditional Japanese houses often use this approach to particularly good effect, and the walls create small enclosed courtyards that can be specially pleasant. It is the essence of amenity in acoustic design to arrange that such noise barriers enhance the enclosed environment in this way.

In buildings such as concert halls, there are fewer disadvantages to using heavy construction materials to isolate the space from external noise. Indeed the obstacles are generally simply financial. The acoustic problems of concert halls are rather those of optimising the internal acoustics to provide the best possible environment for the purpose for which the hall is to be put. In offices and shopping malls it is common to use a quite different approach and to inject masking sound — either background music or spectrally shaped noise. If the background level is

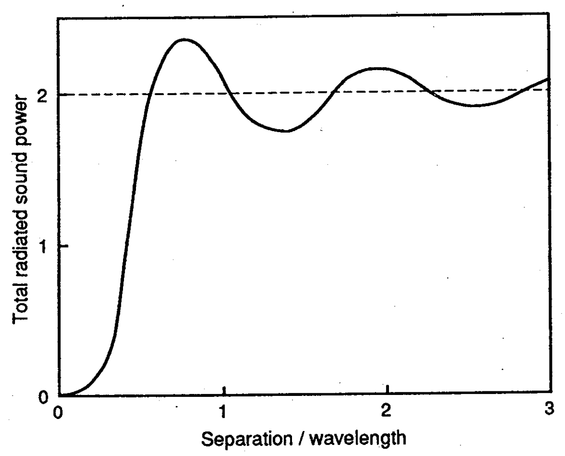


Fig.2 Total power radiated from two anti-phase sources as a function of their distance apart showing cancellation at small separations and addition at large separations.

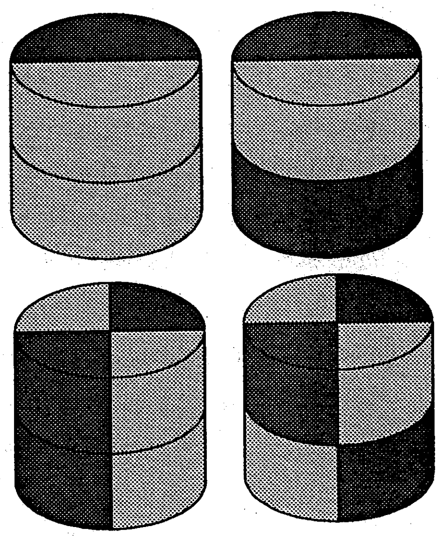


Fig.3 The geometrical patterns of the first few acoustic modes in a cylindrical cavity.

already low, as perhaps in a hospital or executive office, these methods may be very effective. In an environment that is already noisy however, such as a restaurant, the masking sound can become more obtrusive and irritating that the original noise.

An extreme solution would perhaps be to place all dwelling places underground, leaving the surface of the earth for transport. Such a solution, however, would sacrifice access to the visual and natural environments and could hardly be regarded as satisfactory. Nevertheless, underground shopping precincts and similar constructions do have great appeal and perhaps serve to enhance our appreciation of trees and mountains when we return to the surface!

When we come to consider small group environments such as the interior of aircraft cabins, we must look for rather different solutions because of the great penalties associated with increased structural weight. Apart from good engineering design, a promising modern solution is to use some form of active noise control, and it is worthwhile to give brief attention to this. Suppose we have a noise source of very small size, then it is possible to quieten it by placing beside it a sound source that is fed with a signal that is exactly out-of-phase with the original noise. As shown in Fig.2, however, this will work only if the two sound sources are separated by a distance that is a good deal less than half a wavelength for the sound considered. For greater separations, or higher frequencies, the noise powers add rather than subtracting, and a much more sophisticated approach must therefore generally be used.

The prime source of noise in an aircraft cabin is structure-borne vibration of engine noise through the body panels. High-frequency sound can be excluded moderately simply, so that the major problem lies with noise of rather low frequency, but is enters the cabin from all sides, rather than from a single source. This noise has components with air wavelengths that are comparable with the interior dimensions of the cabin, and it is therefore reasonable to analyse its properties in terms of the normal modes or standing waves that can be excited within the cabin space, as shown in Fig.3. The aim of active noise control in this environment is to attempt to cancel out the normal mode excitation by injecting additional sound or vibration, not just at a single point, but at several Carefully chosen points and with appropriately chosen phase relations. This may not reduce the vibration amplitude of the walls, but does reduce their coupling to the acoustic modes of the enclosed air.

Detailed application of these methods to the control of low-frequency sound in enclosures is a relatively new subject, but already impressive results have been achieved in test situations, with level reductions of up to 20 dB. In a real aircraft cabin it will be necessary to have sophisticated adaptive control to determine the amplitude and phase of the cancelling sound and to make adjustments for changes in the environment as people move around the cabin, but this is very nearly within the grasp of contemporary computer algorithms and hardware.

3. THE PERSONAL ENVIRONMENT

The personal environment is the acoustic space in which we live out lives. It is sometimes part of the general environment, sometimes part of a group environment, and sometimes individual in our homes. True amenity in acoustic design should allow us to control that space without trespassing upon the personal spaces of other people.

I have already mentioned the Walkman radio or cassette player as one approach that is particularly successful, and indeed it does nearly all that is required. The headphones exclude much of the environmental noise, the wearer has nearly complete control over the nature and level of the added sound, and little noise is radiated to interfere with others. With the advent of portable CD players of similar pattern, and now of digital audio cassettes, the degree of control available becomes very great. The only problem is the intrusion of environmental noise, an effect that is hard to eliminate with lightweight headphones. The usual solution adopted is to increase the level of the wanted sound so as to mask out the noise, and this is fairly successful, particularly as the increased sound level leads to temporary threshold shift so that the noise itself is less readily perceptible. The problem is that the threshold shift also makes the wanted sound less loud, and there is a psychological need by many people to increase the level progressively to maintain the subjective loudness, with the result that those wearing the device for many hours each day may suffer permanent hearing damage.

For those who require simply a quiet personal environment, the obvious approach is to wear heavier isolating ear-protectors. This is what is done in really noisy environments, such as factories, and a very substantial noise reduction can be readily achieved. A limit is set by the conduction of sound through the bones of the head as well as through the ear cap itself. Such ear protectors give an isolation from the environment that could be hazardous in some cases, but it is simple to build in a communication channel, or even a variety of such channels, with audible short-range warning signals being radiated on microwave or infrared frequencies to the embedded receiver.

Taking another tack, it is possible to build active noise control into ear protectors. Indeed the problem is relatively simple compared to that of active noise control in extended environments because cancellation is required only at a single point — the entrance to the ear canal. Such a noise cancelling system can then be combined with a communication system. An extremely lightweight active system of this kind is certainly achievable and, in combination with a Walkman-type program source and a communication channel, would represent the ultimate in personal acoustic amenity.

To this picture should probably be added other sense channels — particularly vision, but also perhaps touch and smell — to achieve an environment of virtual reality. Developments in this area are progressing rapidly, and I mention only those relating to acoustics. To achieve a sense of virtual reality, even in a purposely distorted environment, requires a good directional simulation for sound impressions. With sound sources in a moderately large acoustic environment such as a theatre, this acoustic orientation is simple to achieve through physical location of the various sound sources. In environments of virtual reality, the sound source is generally a set of headphones, and it is necessary to process the sound in such a way as to mimic the auditory clues that allow us to locate sounds. Some of these are already present as the phase shifts in ordinary stereophonic sound, but others, such as those in the vertical symmetry plane of the body, depend upon more subtle clues such as filter envelopes generated by the geometric form or our external ears. Indeed a truly effective system needs to take head movements into account and feed these back into the audio signal so that the sonic environment remains stationary, rather than rotating with the head.

There is, however, a philosophical point to consider in relation to all these developments. Suppose that we had achieved the ultimate personal acoustic and visual space, completely isolated at will from the environment and with a program source under our immediate control. A great technical achievement, yes, but would this really represent amenity? If we all retreat into our personal environments, what will become of social interactions? Is this already happening with many of today's youth? Will this Brave New World of total amenity defeat its own purpose?

4. ACOUSTIC ELABORATION

Setting aside this unsettling speculation, let us return to a communal acoustic space, which might be as large as a concert hall or as small as a living room, and examine something of the future in relation to its acoustic elaboration. We can assume that all external noise has been excluded, and we wish to create an acoustic environment that we can enjoy with a small or large group of friends. What possibilities might open us?

A completely blank acoustic environment, such as met with in an anechoic chamber, is not only sterile but also psychologically unsettling. We crave a sense of space around us, but also a sense of enclosure, or at least a sense of other objects in our neighbourhood. This is automatically provided by a real enclosure, as in a room, and the size of the room, together with the acoustical properties of its walls, ceiling and furnishings, defines the subjective qualities of the environment. Our own activities then produce sounds which characterise the environment for us, in much the same way as, though with less sophistication than, the way in which a bat uses active sonar for guidance. If our auditory perceptions reinforce our visual perceptions — as when we enter a comfortable living room, at one end of the scale, or a gothic cathedral at the other — then the sense of place is greatly enhanced. If the acoustic environment conflicts with the visual impression, then we sense that something is wrong.

The acoustics of the group environment thus immediately defines a back ground upon which the occupants of that environment impose acoustic signals in many ways. Let me speak only about musical sounds, for they are the sounds to which we generally listen most critically.

4.1 Music Reproduction

One of the most highly developed areas of acoustics is that of music reproduction, and we are certain to see impressive advances in this field over the next decade or so. Some of the technological advances will simply involve the hardware — what I would like to concentrate on are the acoustic aspects of likely developments.

Leaving aside the progressive increase in frequency range and decrease in distortion and background noise level, the greatest advance in music listening over the past fifty years has been the introduction of two-channel stereophonic reproduction. This immediately added immensely to the realism of the reproduced performance. The addition of a third centre channel never proved to be popular, and early attempts at adding two rear channels to provide quadriphomic reproduction have similarly sunk into oblivion. There was good reason for this, particularly in the case of quadriphonic sound, because it attempted to provide a sophisticated acoustic effect by using rather simple technology. With modern digital technology much more is possible.

We should first remember that all musical performances, except those relying upon synthesised electronic music, are necessarily recorded in a real acoustic environment with its own particular characteristics. Conventional recording and reproduction techniques attempt to recreate that acoustic environment in the listening room. With modern digital filtering techniques, however, it is possible, at least in principle, to deconvolve the acoustic effect of the recording environment and to reproduce the "pure" signal originating from the instruments — though there has to be some arbitrariness here, depending upon where we define the instrument to end and the environment to begin. Of course no one would really want to do this, for the sound of an orchestra playing in an anechoic chamber would be very unsatisfactory from a musical viewpoint. Once we have the "pure" sound, however, it is possible to produce the effect of an arbitrarily chosen acoustic environment by digitally convolving the electrical signal with the pre-defined transfer characteristics of that environment. In practice, it is usually enough to take the normally recorded sound and add on the desired extra acoustic effects, because original recordings are usually made in relatively neutral acoustic environments.

Great progress has been made in this field in recent years, and versatile signal-processing amplifiers are now commercially available for home use. To produce impressive results it is necessary to use at least four loudspeakers, two of these being behind the listeners, because the human auditory system is able to make quite good in-front/behind judgments as well as locating sources much more accurately in the forward half-space. The transfer function appropriate to the rear speakers is complex, involving time delays, often of a multiple kind, and filtering in the frequency domain, as well as level adjustment. If the simulated environment has a long reverberation time, the effect of this convolved with the front speaker response must also be taken into account. In a system of the utmost sophistication it should also be possible to adjust for the acoustic is generally fairly neutral compared with that of the simulated environment, this complication can generally be ignored.

In real listening situation, of course, the criterion to be used is not really that the reproduced sound be an accurate representation of the original, but rather that it be a musically satisfying experience. We can certainly contemplate the possibility that a reproduction that is not entirely faithful to the original might be more aesthetically satisfying than the original performance itself. It is surely legitimate to transform the acoustic environment into something of the listener's own making, but the technical freedom to do this must be tempered by restraint if the result is to be aesthetically pleasing.

4.2 Musical Instruments

Since I am discussing music, it is also appropriate to say something about the future of musical instruments. As we gain more and more control over what is possible in music synthesis, will conventional musical instruments maintain their importance? Because I am something of a traditionalist about musical instruments, I am happy to note that, except in the field of pop music, traditional musical instruments appear to be maintaining and even expanding their influence. New concert halls around the world are almost invariably equipped with large new pipe organs that maintain the tonal, and even the mechanical traditions established some 300 years ago; pianos retain their place; harpsichords, recorders and other baroque instruments are more commonly available and more widely played than even before; and there is a great rebirth of interest in playing orchestral stringed and wind instruments. Japan has led in some of these fields through the activities of great teachers and through the efforts of its musical instrument manufacturing companies.

Interest in making and playing the traditional instruments of non-European cultures is similarly being maintained, and sound recordings are fostering this. I believe this to be most important if we are to avoid a dull uniformity of musical culture across the whole world. I hope that the playing of the Javanese gamelin and the Japanese shakuhachi and koto will prosper, not only for the performance of the traditional music of these countries, but also as subtle and distinctive contributions to the palette of available sounds for music of all types.

It is remarkable how resilient is the tradition behind musical instruments. The designs of European stringed instruments have changed little over the past two hundred years, and even woodwind instruments have simply gained some sophisticated keywork to assist the fingers, rather than changing in any fundamental acoustic aspects. Only a few new instruments, such as the saxophone, have really established themselves. The same is true to an even greater extent of non-European instruments.

Part of the reason for this stability is that music is a continuing tradition, and we still listen to a continuous range of compositions from the past four centuries or so. Traditional instruments, it is true, are not simple to play and require long study, but after this apprenticeship the instrument becomes almost an extension of the player, and all the nuances of its performance become nearly second nature.

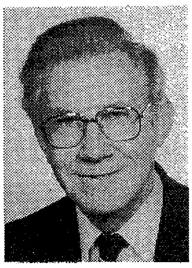
In contrast, most of the more radical modern musical instruments lose this immediacy. Keyboard synthesisers, it is true, maintain something of the structure and technique of the organ, and electric guitars have something in common with acoustic guitars (except in the music they play!), but the more abstract computer-based instruments so far remain the province of composers, who construct music either by formal rules or by a sort of cut-and-paste technique which departs from the tradition of musical performance. I do not say that this type of music is necessarily inferior on that account, but it has yet to produce a great composer.

It is, I suppose, possible to think of an intuitive musical instrument, responsive to all the movements of the player's body and able to be controlled in a precise and flexible manner, which might ultimately replace traditional instruments. The problem is to combine the necessary precision of note duration and pitch, which argues for some sort of control mechanism in a relatively fixed configuration and responsive to finger movement along its surface, with a more flowing dynamic and tonal response that follows signals from a larger part of the body — moving arms or legs, breath pressure, or something similar. Conventional musical instruments achieve these aims in an economical fashion and also give aesthetic pleasure because of their intrinsic tonal and dynamic limits. While they may not all reach the Japanese ideal of *shibui*, it is only through restraint that artistic satisfaction can be achieved.

5. CONCLUSION

As we approach the twenty-first century, our human senses are bound to be increasingly assaulted by noise and by intrusive sounds of other kinds. It is vital to our collective and individual peace of mind that we develop acoustic environments, for private and public spaces and for the outside landscape, that preserve their amenity. To do so will require careful planning at public level, sophisticated engineering, and a resistance on the part of informed members of the public to the acceptance of progressively degraded standards. Noise seems inseparable from material progress, but al least we can try to minimise its impact by using the best available technology.

As well as this protective use of our science on behalf of humanity, new technology also gives us increasing ability to enhance our individual acoustic environments so that they serve as well as possible for relaxation, for communication, of for aesthetic enjoyment. All these uses of technology are good but, as in everything, we must be careful of excess — excessive reliance on technology can reduce, rather than enhance, our humanity.



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