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EDITORIAL

This is a special 12th International Congress on Acoustics issue of CANADIAN ACOUSTICS. It is special because it contains three invited papers in place of the normal contributed papers, and because we are giving a copy to each attendee at the 12th ICA. If you have received this copy at the ICA, we would like to welcome you to Canada and we hope that your visit will be both pleasant and rewarding. We hope that this issue will help you to learn a little more about acoustical activities in Canada.

This issue contains papers on factory acoustics, underwater acoustics and hearing research. It also contains the results of our survey of Canadian acoustical consultants, news of a new Canadian standard on the measurement of occupational noise, and a book review. Of course, there is also our usual news material, and our calendar of acoustical events.

CANADIAN ACOUSTICS is published quarterly by the Canadian Acoustical Association. We publish refereed papers and news items on all aspects of sound and vibration. Papers are published in either French or English with an abstract in both languages. If you are a visitor perhaps you would like to consider submitting an article to CANADIAN ACOUSTICS on your own research or a review of some area of acoustical activity in your country. Although all papers are reviewed, the process is very efficient and papers are normally published within a few months of the initial submission. We would certainly welcome a submitted paper or even news material from you. Should you wish your library to subscribe to CANADIAN ACOUSTICS, there is an application form at the back of this issue.

EDITORIAL

A l'occasion du 12e Congrès International d'Acoustique, nous publions un numéro spécial de l'ACOUSTIQUE CANADIENNE. Les contributions habituelles sont remplacées par trois articles invités qui portent sur le système auditif, l'acoustique sous-marine, et l'acoustique des usines. Ce numéro contient également les résultats d'une enquête sur les services de génie conseil en acoustique, des détails sur une nouvelle norme canadienne sur la mesure du bruit en milieu de travail ainsi que les rubriques habituelles.

Ce numéro sera distribué gratuitement à tous les participants du 12e ICA. Si vous êtes parmi ceux-ci, nous vous souhaitons une chaleureuse bienvenue au Canada et nous espérons que vous y passerez un séjour agréable et profitable. En vous offrent ce numéro nous voulons vous donner un aperçu partiel des activités en acoustique au Canada. Evidemment il est impossible de décrire toutes nos activités en acoustique dans un seul numéro.

L'ACOUSTIQUE CANADIENNE est publié quatre fois par année par l'Association Canadienne de l'Acoustique. Nous publions des articles et des informations sur tous les domaines du son et des vibrations. Tous les articles sont arbitrés. Ils peuvent être rédigés en français ou en anglais, mais doivent être accompagnés d'un sommaire bilingue. Si vous êtes de l'extérieur du Canada nous vous invitons à soumettre un article à l'ACOUSTIQUE CANADIENNE portant sur les résultats de vos recherches ou un aperçu approprié des activités en acoustique dans votre pays. Vous trouverez les informations pour la préparation des manuscrits à la fin de ce numéro. Vous trouverez également un formulaire d'abonnement.

AMBIENT NOISE IN SHALLOW WATER: A LITERATURE REVIEW

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ABSTRACT

The article reviews the literature since 1962 on underwater ambient noise. Particular attention is paid to those factors which influence noise levels and directionality in shallow water. Infrasonic noise, seismic noise in the sea bed, ship generated noise, and wind generated noise are considered. Noises of biological origin are acknowledged but not described in detail. The importance of understanding sound propagation phenomena, including bottom interaction, and of modelling is discussed. Suggestions for future research on shallow water noise are offered.

SOMMAIRE

L'article passe en revue la littérature sur le bruit ambiant sous-marin publiée depuis 1962. On paie une attention particulière aux facteurs qui influencent le niveau et la directionalité du bruit ambiant en eau peu profonde. On considère les régimes infrasonique et séismique, aussi bien que le bruit produit par le traffic océanique et l'intéraction du vent avec la surface de la mer. Le buit d'origine biologique est reconnu, mais n'est pas considéré en détails. On discute de l'importance de comprendre les phénomènes de propagations, comme l'influence du sous-sol sous-marin, ainsi que de développer des modèles environnementaux du bruit. On offre des suggestions pour de futures recherches dans ce champ.

1. INTRODUCTION

1.1 Motivation

As greater use is made of the underwater environment, a detailed knowledge of underwater ambient noise is necessary. Ocean ambient noise constitutes a background noise in measurements for fisheries, oceanographic or oil exploration purposes. It is also a limiting factor in the performance of acoustic instruments and in the control by acoustic means of research instrumentation. Moreover, the ambient noise in itself may be of biological or oceanographic interest. An interesting recent example is infrasonic noise, which has been found to be related to microseisms. Both infrasonic noise and microseisms are caused predominantly by non-linear wave-wave interactions, a subject which is attracting growing attention.

The fact that most fishing and oil exploration activities take place in the shallow water areas corresponding to the continental shelves justifies the need for a detailed description of the acoustic ambient noise in shallow water. Much effort has been expended in measuring and modelling the characteristics of the propagation in shallow water ocean areas, with much success. However, a proportional effort has not been invested into investigating the shallow water noise field, especially with respect to directionality. Moreover, special efforts are needed in shallow water because of the inadequacy of deep water methods when applied in shallow water.

In the military context, the development and improvement of acoustic detection and localization systems depends on this knowledge. The more that is known of the noise and signal characteristics, the better detection systems can exploit their differences to improve the signal-to-noise ratio. These include such differences as spectral shape, spatial distribution and coherence, cross-correlation spectra, etc., between the signal and the noise.

The present review brings together much of the open literature on ambient noise in shallow water, and some representative results in deep water when relevant to the discussion. It reports an emerging consensus on identifying the important factors affecting ambient noise levels and coherence. The main areas of possible research on underwater ambient noise relate to its dependence on time and location, its directional distribution, both vertical and horizontal, and its sources. A good understanding of the mechanisms contributing to ambient noise production helps us to model and predict the ambient noise characteristics in a given area, so we need not rely solely on empirical models. This is one reason why research is done in mechanisms of noise generation.

1.2 Definitions: ambient noise and shallow water

We will use the following definition of ambient noise: ambient noise is the acoustic part of the signal after the contributions from obvious identifiable sources have been removed. The latter can be considered as interference rather than noise. For example, the sound radiated by a nearby ship does not constitute ambient noise, but the noise generated by a distribution of several distant vessels does, and is called shipping noise. The pseudo-sound caused by turbulent pressure fluctuations on a hydrophone in a current, called flow noise, does not qualify either, because it is not acoustical (radiating) in nature. However, because flow noise is difficult to separate from ambient noise, measurements of the ambient noise have often been contaminated by flow noise. Therefore results from studies on flow noise have been incorporated in this review.

Shallow water areas are generally thought to include all of the continental shelves, but can not be defined uniquely in terms of depth. Frequency is an important parameter too. What most characterizes shallow water acoustics is not only the occurrence of multiple bottom bounce paths, which may occur as well in deep water, but also the interference effects they produce in travelling sound waves. When the acoustic wavelength is of the same order of magnitude as the water depth, one is facing a shallow water environment. This means that at 1 Hz and below all the oceans on earth can be considered shallow water. On the other hand, one can consider a large, 50 meter deep lake to be a deep water environment when using a 10 kHz sonar to map the bottom.

This paper concerns ambient noise in shallow water, where shallow water is defined by wavelength comparable to depth. In the great majority of the cases considered in this review however, it can be assumed to correspond to the continental shelves. Although most of the important characteristics of the production and propagation of noise in deep water may also be found in shallow water, the multiple interactions of sound with the bottom makes the shallow water environment more difficult to analyze and model.

1.3 Normal modes

When the dimensions of the acoustic channel are not very large compared to the acoustic wavelength, one must use wave theory to describe the acoustic field. One representation of the solution to the wave equation with boundary conditions constitutes normal mode theory. Most shallow water models are based on normal mode theory. The simplest and the first such model is the Pekeris model (Pekeris, 1948), consisting of a homogeneous fluid layer overlaying a liquid half-space of higher impedance. The part of the solution corresponding to transported energy is expressed in terms of a sum of functions describing vertical pressure variations, called normal modes. A normal mode propagates in a given channel for each incidence angle of the travelling wave which leads to constructive interference. A wave impinging on the bottom and surface with an angle in between two of these discrete values will be damped out. The number and shape of the modes are determined by the depth of the channel, the bottom composition, and the frequency of the acoustic wave. The upper limit of possible grazing angles between the acoustic rays and the horizontal is called the critical angle and depends on the composition of the bottom. For a grazing angle greater than the critical angle, some energy is lost into the bottom at each bounce and the corresponding ray attenuates with range much faster than the normal modes. At close range to the source, these rays may constitute a significant portion of the acoustic field and may not be ignored. At longer ranges this continuum of rays may be sufficiently attenuated so the normal modes satisfactorily describe the significant portion of the acoustic field. Figure 1 illustrates the geometry of

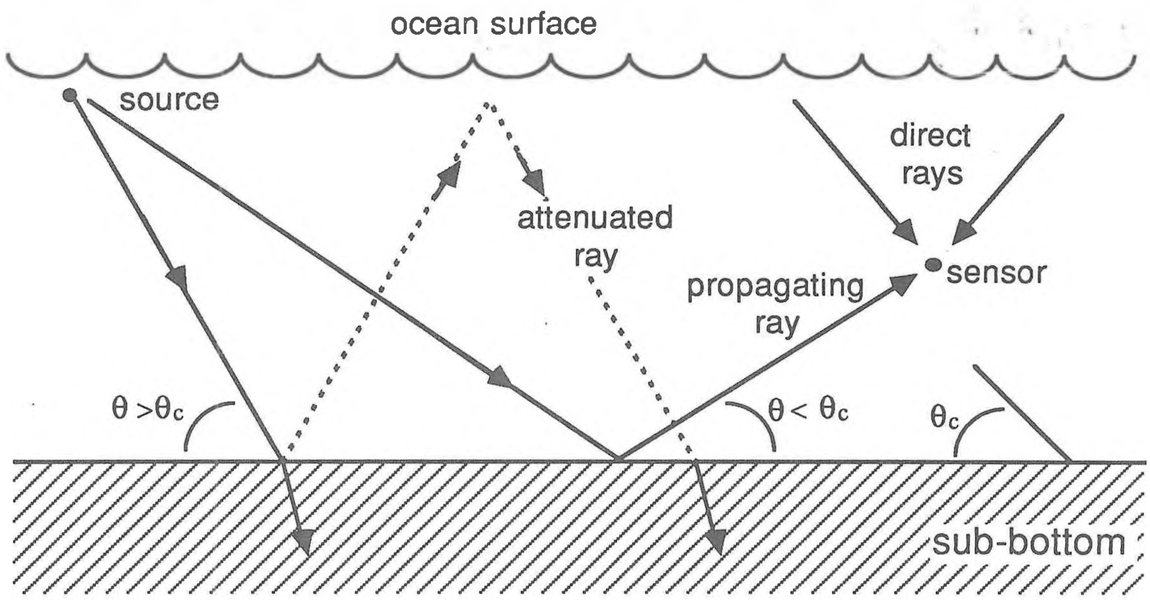

Figure 1. Geometry of propagating and non-propagating rays in shallow water.

these different cases. For a detailed exposition of the theory of normal modes in shallow water, see (Tolstoy and Clay, 1966).

1.4 Shallow water acoustics versus deep water acoustics

It is important to distinguish the differences between shallow and deep water from the acoustical point of view. Several factors cause the shallow water acoustic environment to be more variable (in both space and time) than the deep water one. Firstly, because of the generally strong interactions of the acoustic waves with the seabed, the acoustic properties of the seabed are a prime consideration in describing the propagation characteristics of shallow water. However, the bottom composition and structure are generally poorly known, highly variable from place to place, and reliable data are often difficult to obtain. Secondly, the sound speed profile of the water column itself shows great variability in time and space, not only seasonal and diurnal, but also depending on the weather. This happens when the sun heats up the upper surface layer, or a storm mixes uniformly the whole water column. In the deep ocean, only the topmost layer is affected by these phenomena.

Another difference between shallow and deep water has already been mentioned, and is the normal mode versus ray propagation. This point is all too often overlooked when dealing with shallow water environments. This means that the intensity, phase and coherence of sound waves may display depth dependence rapid enough to be noticeable across an acoustic array. The use of standard beamforming methods in such a case would then result in some degradation of the array response.

1.5 Outline of this review

In Section 2, we will examine results of ambient noise measurements, starting with Wenz's 1962 review, concentrating on concepts relevant to shallow water acoustics but neglecting deliberately the literature relating to ice produced noise, which forms a field of study on its own. Section 3 describes the ambient noise models, which bring observations and theories together in trying to predict ambient noise levels and array performance in shallow water. In the Conclusions, we will review what is known, state some of the outstanding questions, and propose a few new topics for research.

2. EXPERIMENTAL RESULTS

2.1 Previous reviews

One of the most well-known and thorough reviews of underwater ambient noise is the one undertaken by Wenz (1962). It still stands as a cornerstone of the field. Wenz brings together, compiles and compares the results of several investigations, and proceeds to classify the different regions of the noise spectra according to their types and sources: wind-dependent, wind-independent and low-frequency. It is worthwhile to review his major observations, both as a basis of comparison of more recent work, and for its instructiveness. Two other reviews are included in this literature survey, one by Wenz (1972), and one by Urick (1984). Let us start with Wenz's first review.

2.1.1 Wenz's review

The infrasonic region is usually defined to include frequencies from 1 to 20 Hz. The small amount of data available at the time of Wenz's first review shows very little wind dependence in this range, with a slope of -8 to -10 dB per octave. Ocean surface waves can be an important noise source in this frequency range. Hydrostatic pressure variations proportional to water level can be important in shallow water (for depth < ~100 m). Experimental data show a high correlation between the acoustic energy flowing in the water and the seismic energy flowing in the bottom. The direction of the flow of energy was not known at the time Wenz wrote his review.

Wenz brings attention to a mechanism for low-frequency wind-independent sea noise: turbulence in the water around the hydrophone. Wenz estimates the pressure fluctuation amplitude and plots the resulting spectra for different values of the oceanic current.

Wind-generated ambient noise is situated in the range 50 Hz to 10 kHz, with a broad maximum between 100 and 1000 Hz. The main source is thought to be the oscillation of air bubbles from surf or breaking waves. Wenz reports the results of several studies and measurements of generation of sound by air bubbles or cavitation. There is evidence to support the existence of microbubbles in the sea even when the wind is low. Another wind-dependent source Wenz pointed out is water droplets hitting the surface from spray or rain.

The wind-independent ambient noise is detected in the region 10 to several thousand Hertz and therefore partly overlaps with the wind-dependent noise component. It is produced by both biological sources and oceanic traffic. Wenz distinguishes between *traffic noise*, which comes from a number of ships travelling a large distance from the listening station, and *ship noise*, which comes from one or a few ships at relatively close range.

Noise of biological origin has been observed within the whole range of frequencies covered by then available systems, from 10 Hz to 10 kHz. Most of the biological noise is made of transient sounds; clicks, whistles, etc., which are often repeated and can even sound like a continuous sound as in the case of the crackling of snapping shrimp. The biological noise spectrum varies with time and location, and can show diurnal or seasonal patterns. Most of the time, biological noise can easily be recognized, due to its transient nature, but the source might be hard to identify.

Major topics which are not covered in Wenz's 1962 review, because of lack of data at the time, are the temporal and spatial characteristics of ambient noise.

Wenz's 1972 review is more limited in scope, focusing mainly on the historical development of research in sea ambient noise. Some valuable recommendations for future research are given toward the end of his article. Among the new material included in this 1972 review is some material on noise directionality in deep water and correlation between power spectrum levels and environmental factors. We will come back to these developments in detail later on.

The most recent in-depth review of the research on underwater ambient noise noted by the author was by Urick (1984). Urick's review includes the sources and variability of ambient noise, its dependence on receiver depth, the directionality and coherence of noise in deep water, biological noise and noise in the Arctic. What is not covered in his review is the directionality and coherence of noise in shallow water, and environmental modelling. One of his comments about shallow water ambient noise is:

> *In shallow water, in the absence of local shipping and biological noise, wind noise dominates the noise of distant shipping over the entire frequency range. The reason for this is that the deep favorable propagation paths traveled by distant shipping noise in deep water are absent in shallow water; in other words, the poor transmission in shallow water screens out the noise of distant ships and allows locally generated wind noise to dominate the spectrum at all frequencies.*
>
> (Urick, 1984, page 2-33)

However, shallow water areas include some regions of very intense shipping and oil exploration. These regions often have ambient noise levels well in excess of those found in deep water. Therefore, the local shipping condition is another factor which causes site dependency in shallow water.

2.2 Noise levels in shallow water

2.2.1 Acoustic data

The basic features of Wenz's 1962 review are still very relevant today. However, considerably more knowledge of the "grey areas" has been obtained since then. This includes the very low frequency spectrum (infrasonics) and the statistical properties in the time domain of the noise field. A compilation of ambient noise power spectra from Kibblewhite and Ewans (1985) and Ross (1976) is shown in Figure 2.

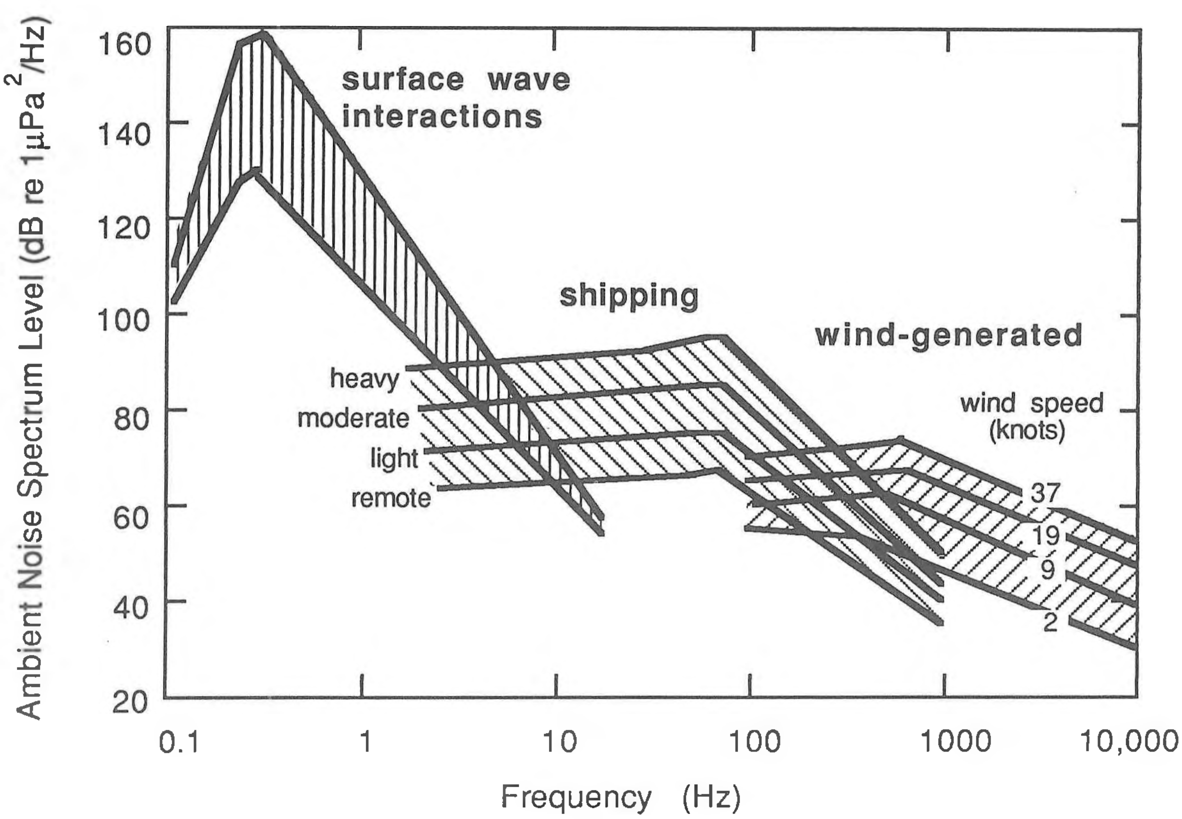

Figure 2. Underwater ambient noise power spectra.

Shipping and wind-generated noise levels are representative of those met in *deep* water. In his 1962 review, Wenz observes that the shallow water noise levels are in general about 5 dB higher than in deep water, for corresponding wind speed. He attributes this difference to turbulence and current, industrial activities, and at very shallow depth (50 m or less), to hydrostatic pressure changes due to surface waves.

Piggott (1964) conducted an ambient noise measurement with 2 bottom-mounted hydrophones connected to shore by a cable, in 36 m and 51 m of water. He finds that the noise level varied linearly with the logarithm of the wind speed, and that it was season dependent. His proposed explanation is the change in temperature profile in the water column. An important point is that his spectral curves agree in shape (i.e. slope) with Wenz's, but Piggott's results are 2-7 dB higher than what Wenz predicts, depending on the wind. Finally, the deeper hydrophones had noise levels 2-3 dB lower than the one at 36 m, indicating a dependency on water depth.

Urick (1971) made a comparison study at two contrasting shallow water sites, whose principal characteristics were: one off the coast of Florida, with a high ship traffic and a poor sound propagation due to a downward refracting profile; the second in the Gulf of Maine with good propagation conditions due to a sound channel, and little or no traffic. Comparison of the mean spectra shows that the Florida site is noisier by 5 to 10 dB than the Maine site at low frequencies (50-500 Hz), but only slightly noisier at higher frequencies. The high ship traffic at the Florida site is claimed to be responsible for the higher noise level there, but only the sources situated within approximately 5 miles of the hydrophones contributed to the ambient noise, in clear contrast with what happens in deep water. However, the wind-dependent noise at high frequency is found to be the same at both the Florida and Maine sites. Urick's conclusion is that the high-frequency wind-generated noise "*doubtless originates at the sea surface in the immediate vicinity of the measuring hydrophone.*"

An experiment designed to test Wenz's hypothesis that current turbulences produce the low-frequency noise (below 10 to 30 Hz) was conducted by Bardyshev, Velikanov and Gershman (1971). They measured ambient noise at depths of 100 to 130 meters, where tidal currents reached a maximum of 0.78 m/s. They find that the use of current shields reduces the pseudonoise level by 10 to 24 dB in the frequency range 2 to 20 Hz for a flow velocity of 0.6 m/s, without attenuating the sound signal. The slope of the spectrum is considerably lower than the one reported by Wenz, at -3.5 to -5 dB/octave.

Nichols (1981) had one of his hydrophones in 13 m of water, the others at 300 and 1200 m. The shallower one showed higher noise levels at low frequencies ($f < 5$ Hz), and a higher standard deviation (5 dB against 2 to 5 dB for the 300 m hydrophone). Nichols used current shielding cases for housing his hydrophones. He did not record wind speeds or bottom ocean currents, but nonetheless infers from comparison with diverse theories of noise generation that, for the frequency range 0.1 to 10 Hz, the likely noise source was non-linear wave-wave interactions.

Worley and Walker (1982) made measurements in the Gulf of Maine with bottom mounted hydrophones in the frequency region 50 to 800 Hz during an 18 month period. They report unusually low levels of ambient noise, highly correlated with wind strength over the whole spectrum. Transmission loss measurements show a very high acoustic attenuation, of the order of 100 dB at 2 miles. Refraction profiles indicate an unconsolidated sediment layer a few tens of feet deep over rock. Shear waves in the rock are suggested as the reason for the high loss. Measurements at another site where transmission loss was lower show much higher noise levels, which are wind-independent below 500 Hz. The conclusion from their study: noise level and significant source are dependent on transmission properties of the bottom.

Another study which came to the same conclusion was conducted by Wolf and Ingenito (1982). They compile the results of ambient noise measurements during equivalent sea-states taken at widely different sites. They find that the noise levels can vary by as much as 15 dB between sites.

In complete contrast to this last study are the conclusions of Wille and Geyer's experiment (1984). They conducted shipborne ambient noise measurements in the Baltic Sea and the North Sea. The sites had different depths (90 m vs 46 m), different thermoclines and different bottom types (mud versus sand and gravel). They recorded the ambient noise in the region 25 Hz to 12.5 kHz. They conclude that "*...even extremely different propagation conditions in shallow water cause no more than marginal changes of the wind-dependent noise level.*" Their conclusion is in such opposition to other measurements and studies that one cannot help but look for an explanation, either in their experimental set up or their analysis method. One important difference in their recording equipment is that they used hydrophones suspended 40 m above the sea bottom by buoy. This can have two effects: to induce a greater amount of flow noise than a bottom mounted hydrophone would experience, and to diminish the effect of the bottom as a noise attenuator. Another point is that their two sites might have been too different, preventing a control of the effect of each variable. In other words, the different effects might have canceled one another. It would be instructive to check this possibility by simulating the environments of the sites they used on an ambient noise model.

Kuperman and Ferla (1985) measured the depth dependency of wind-produced ambient noise at a shallow water site. They find that the noise level was constant with depth to within a couple of decibels. They then fed the noise levels into an ambient noise model of shallow water, together with propagation measurements in the area, to calculate the source strength of wind-generated noise. The resulting source strength can be used by their model to predict the ambient noise at any other shallow water location, given the propagation parameters.

2.2.2 Seismic data

An ambient noise study with both ocean bottom seismometers (OBS) and hydrophones was conducted by Brocher and Iwatake (1982) with the purpose of identifying the various sources of noise. The technique they used did not give absolute noise levels, only their variation in time. They find that above 6 Hz, their records show no correlation with the wind data. However, between 1 and 2 Hz, the ambient noise levels (in decibels) are linearly correlated to the logarithm of the wind speed with a proportionality coefficient of 2.4 ± 0.4. They attribute this noise to turbulent pressure fluctuations (Wilson, 1979). Comparison of the hydrophones and geophones shows that on the continental shelf, "*...the ambient pressure fluctuations were larger and more numerous than those recorded by the geophones; on the continental slope (deep water), the opposite was observed. The origin of this discrepancy is unknown.*" They report some events which are consistent with being generated by bottom currents, lasting usually on the order of a few minutes. Nearby airgun profiling plagued 2 of their 5 $^1/2$ day study. Ship traffic was another important source of noise, and its level was up to 11 dB above the ambient noise, dominating it for less than one percent of the time. A high level of biological activity is identified in the form of short (less than 5 s) impulses recorded by the geophones, but not by the hydrophone. This indicates that the noise was not acoustic in nature, but rather was generated by organisms touching the OBS. Because these events dominated up to 17% of the time, their existence must be taken into account when interpreting data from OBS ambient noise measurements. Seismic events amounted to only 0.7% of the time during the 2 day study.

One ground-breaking experiment concerning the origin of low-frequency ambient noise and microseisms was conducted by Kibblewhite and Ewans (1985). They wanted to further investigate the close relationship between sound pressure on the sea floor and low amplitude seismic activities, known as microseisms. Its is known that non-linear wave-wave interactions (Goncharov 1970, Hughes 1976) are not attenuated with depth and are significant at all sites (Harper and Simpkins, 1974). Kibblewhite and Ewans recorded ambient noise with seismometers based both on the ocean floor and inland. The area they chose to perform the experiment (off the west coast of New-Zealand) is particularly well suited for such a study, because of the regular pattern of winds which often swing rapidly through 180°, creating opposing seas. The depth at the experiment site was 110 meters. They recorded wind speed and direction hourly, air and sea temperature, and the wave height and direction.

The important theoretical characteristics of the non-linear wave-wave interactions Kibblewhite and Ewans were trying to establish are that the frequency of the generated sound field is twice the frequency of the generating surface wave, and proportional to the square of the wave amplitude (Brekhovskikh, 1966; Lloyd, 1981).

Kibblewhite and Ewans' results are striking: "*...comparison of any sea spectrum and its seismic equivalent will identify peaks in the wave spectrum with corresponding peaks in the microseism spectrum at or very close to twice the frequency.*" The microseisms appear in the range 0.05 to 1.0 Hz.

Very intense microseism activity was recorded by Kibblewhite and Ewans, both on land and by the OBS during each of the several times when the wind shifted direction 180°, then dropped, as the new sea entered a steady state, even though the wave levels were still as high. The authors explain the high noise to wind correlation by the lag between wind-change and sea change. Under variable conditions, the microseism and low-frequency ambient noise correlate better with wind speed and direction changes than with the sea itself. By plotting the logarithm of microseism amplitude against the logarithm of ocean wave amplitude, Kibblewhite and Ewans find a slope of 2.06 with a correlation coefficient of 0.81, thereby confirming the square law relation. Kibblewhite and Ewans' final conclusion is that wave-wave interactions are the dominant mechanism of noise generation from 0.1 to 5 Hz.

2.3 Noise directionality

Very little experimental work has been published about noise directionality in shallow water, even though a number of models of vertical directionality in a waveguide have been flourishing in the past few years. The major development has been the realization that the bottom parameters are crucial in determining the ambient noise characteristics. During earlier attempts to describe ambient noise in shallow water, the depth or location dependency was often overlooked, in an attempt to extend the homogeneity condition of deep water acoustics. One example of this is the Ross and Bluy (1976) measurement of ambient noise correlation as a function of hydrophone separation. It is worth noting theirs is the only paper I have found presenting experimental results on ambient noise vertical directionality in shallow water, and even it is unpublished. They measured the cross-correlation between hydrophones, and then proceed to plot the correlation of the sound field as a function of separation between sensors. In doing so they implicitly make the assumption that the noise field was homogeneous throughout the water column. However, if the channel cannot support enough modes (> 10 modes) or if the seabed has too high an absorption coefficient, the field is probably not homogeneous. The case Ross and Bluy studied does not necessarily meet these conditions, especially at low frequencies. It retrospect, it appears necessary to take into account the depth of each hydrophone pair, and show explicitly the depth dependence of inter-sensor correlation.

Horizontal arrays can be used in ambient noise measurements in order to isolate different noise sources, such as ships, whales, on-shore activities, etc. One such measurement was performed off the California shore by Wilson, Wolf and Ingenito (1985) to determine the proportion of noise contributed by breaking surf on the beach. During heavy surf, at 9 km from shore, there was a difference of 10 dB at 300 Hz between beams directed toward shore and seaward. This suggests that a significant portion of the ambient noise on the continental shelf might originate from the beach, and therefore create anisotropy of the noise field in the horizontal.

Schmalfeldt and Rauch (1980) used an OBS to measure the horizontal directivity of ambient noise, as well as its spectrum. The ambient noise is slightly directional, and has a spectrum very similar to the one recorded by the accompanying hydrophone. The ship noise could easily be picked up at a distance of 1 km by the geophone, and its bearing calculated by the polarization of the interface wave propagating at the bottom-water boundary.

2.4 Flow noise

The fact that current turbulence is an important source of noise at low frequencies was suspected by Wenz (1962), and verified by Bardyshev, Velikanov and Gershman (1971), as described in Section 2.2.1 This means that the infrasonic part of the acoustic data presented in Wenz's paper might have been contaminated by flow noise.

To quantify the contamination of ambient noise data by flow noise, McGrath, Griffin and Finger (1976) measured the pseudo-noise caused by the relative motion of water past a hydrophone in a tank. The relative current varied from 0.25 to 0.45 knots. It gave rise to sound pressure levels of 105 dB//μPa for a current of 0.4 knots at 1 Hz, and 91 dB for the same current at 2 Hz. This represents a slope of 14 dB/octave. These levels are at the lower limit of recorded oceanic ambient noise as cited by McGrath (1975).

With the intent to verify whether or not their ambient noise measurement was contaminated by non-acoustic noise, Buck and Greene (1980) measured the cross-correlation of two hydrophones independently suspended from the ice-covered surface at 60 meters from each other. Since the inter-sensor separation was 0.04 wavelengths at 3.2 Hz, a near perfect correlation would be expected at this frequency when the recorded signal is purely acoustic in nature. The average correlation coefficient was 0.8 with a standard deviation of 0.23. The minimum correlation was 0.19, indicating a very high contamination by non-acoustic noise. Unfortunately, they did not have a current meter available, and therefore could not measure any possible cause to effect relation between the two. They verified however, that the cross-correlation was not related to the wind speed or direction during the time of their experiment.

Cotaras, Merklinger and Fraser (1983) also applied the inter-sensor coherence technique as a verification that their ambient noise measurements were not contaminated by flow noise.

In view of the above results on flow noise, it is recommended that future measurements of ambient noise in the infrasonic range should include also an assessment of inter-sensor correlation whenever possible. Such precautions should become the standard in infrasonic noise measurements.

3. ENVIRONMENTAL MODELLING

In their quest for understanding the factors which contribute to and influence underwater ambient noise levels and directionality, researchers in the field increasingly have made use of environmental models in the past few years. These models have three parts. First, a spatial distribution of noise sources (i.e. wind, ships, etc.) is specified, as well as the location and depth of the receiver. Second, the source levels, depths and directivity patterns are specified. And third, a propagation model is applied between the source distribution and the receiver. If the propagation model includes calculation of the phase of the sound waves, then the response of several hydrophones can be combined to model the response of an array. Such models can be used for several purposes.

One of the applications of environmental models is that they can predict high noise areas or directions where search for signals of interest would be very difficult. Another application is to model the response of different acoustic listening devices, with the aim of improving system performances. Finally, the conjunction of ambient noise source models and propagation models can lead to an improvement of both through comparison with measurements.

The ambient noise level models developed for deep water are not adequate for shallow water environments without one important modification: the substitution of a shallow water propagation loss model. Such a propagation loss model takes into account the effect of the presence of the bottom on sound propagation, in terms of the bottom density and velocity profiles, and can incorporate additional factors such as shear waves, roughness, etc.. The two other elements of an environmental model, i.e. source levels and source distribution, remain unchanged. But because of the difficulty of gathering complete data about the acoustic properties of the bottom and due to the variability of the bottom, shallow water models will usually be less reliable than their deep water equivalents.

An environmental acoustical modelling program has been under way at the SACLANT ASW research center since about 1977. All of the three models discussed below use the Kuperman and Ingenito (1980) noise model as their propagation loss component. The random noise sources are represented by an infinite sheet of monopoles located at an arbitrary depth below the surface. The reflection of the emitted sound waves upon the surface couples with the source to produce dipole sources, which is the source behavior needed to account for experimental results.

Jensen and Kuperman (1979) describe the propagation models in use at SACLANTCEN and the first results from noise modelling. Their noise model includes the near-field solution of the wave equation, such as direct path or one bottom bounce, as well as the far field (normal modes). They obtain the signal-to-noise ratio and the correlation function between two sensors at arbitrary positions as a function of depth.

A more complete description of a model called RANDI II and its results are presented by Hamson and Wagstaff (1983). It is an extension of the one by Jensen and Kuperman described above, and it can perform either coherent or incoherent mode summation. Several sample outputs are presented, as well as comparison with measurements at two different sites. Ambient noise measurements were performed at these two sites using a towed array, and their environment was simulated by RANDI II and then compared. The first site was in a deep water basin. The second site was 130 m deep, situated near the edge of the continental shelf. The bottom was composed of sand and rock in the shallow water region. Previous propagation loss measurements concluded that shear waves must be included in the rock to account for the results. The ship distribution was recorded by an aerial survey taken during a previous trial, and was assumed to be representative of the ship distribution at the time of the trial. This latter point diminishes the value of the comparison between measured and modelled ship noise directivity.

Hamson and Wagstaff give some examples of the theoretical response of vertical and horizontal arrays. For the vertical array, the shipping and total ambient noise are displayed separately. The interesting point is that for the particular case they study, most of the shipping noise comes from angles close to the horizontal, and most of the wind-induced noise comes from angles close to the vertical. The results are encouraging. Their model is able to reproduce most of the features of the measured noise distribution, leading the authors to the conclusion that "*...the response of other sonar systems operating at this site could therefore be predicted with some confidence*".

The latest addition to the SACLANTCEN shallow water ambient noise simulation study was by Hamson (1985). She studies the theoretical response of a vertical array to wind-generated noise as a function of the source directionality, the bottom composition and the sound-speed profile of the water column. She uses the parametrization of Liggett and Jacobson (1965) to characterize the noise pressure directionality, which is of the form $\cos^m \alpha$, where the source directionality parameter $m \geq 1$, and the angle α is taken from the vertical. Results are presented for values of m=1, 2 and 3. A value of m=1 corresponds to uncorrelated sources in the Kuperman and Ingenito noise model, and to dipole sources in general. She assumes a unit source level, to allow the effect of various parameters to be studied. Absolute noise levels can be found for different wind speeds by using a frequency-dependent scaling factor.

After comparing shallow and deep water results, Hamson concludes that the noise levels in shallow water surpass those in deep water by approximately the contribution of the normal modes. In some cases, like hard bottom and winter conditions, high noise intensity is found within 30° of the horizontal. This is in striking contrast with deep water acoustics, where wind-generated ambient noise is 3-D isotropic or has a bias toward the overhead vertical.

Hamson finds that the determining parameters of array response are the directionality parameter m and the bottom type. The effect of increasing m is to reduce the discrete mode component relative to the continuous field. This comes about because of the greater amount of energy sent toward the bottom (low α) for higher m. This effect is more pronounced for soft bottoms, where absorption is higher.

Buckingham (1980, 1985) has been doing acoustic environmental modelling of shallow water using a few simplifying assumptions allowing him to derive interesting results without the need for numerical propagation modelling on computer. His aim is to derive general features of the ambient noise in shallow water. Hence he makes the assumption that the sound speed is the same throughout the water column (isospeed). This assumption is not considered critical to the generalization of his conclusions.

Guided by the conclusion of Kuperman and Ingenito (1980) that the ambient noise is dominated by distant sources when the bottom is a low-loss boundary, Buckingham assumes that "*Continuous radiation from nearfield sources may be neglected and that the only significant contribution to the noise field is in the form of modal energy from more distant sources.*" This condition must be respected when considering the range of application of the model's conclusions.

Buckingham (1980) concludes from his model that, away from the boundaries, the noise field can be considered quasi-homogeneous if the channel supports a number of modes greater than about ten. This implies a considerable simplification in the description of the noise field spatial characteristics. The noise is found to arrive at a number of discrete angles on each side of the vertical, up to a maximum angle of $(\pi/2-\theta_c)$ where θ_c is the critical angle of the bottom, defined in Section 1.3. Each angle of arrival to the sensor corresponds to a pair of plane waves arriving on each side of the horizontal. The pairs of waves coming at the lowest angle corresponds to the first mode, the second pair to the second mode, etc.. This is one case where a direct correspondence can be established between normal modes and plane waves.

Buckingham extends his shallow water ambient noise model to a wedge-shaped ocean in his 1985 paper. Again, he finds that, away from the boundaries and if a sufficient number of modes can propagate, a zone of quasi-homogeneity exists.

In an attempt to measure the source level of wind-induced ambient noise, which is an input of any environmental model, Kuperman and Ferla (1985) conducted an experiment in a shallow region of the Mediterranean Sea. They collected ambient noise during five consecutive days, as well as recording wind speed, wave height, and propagation loss data. By comparing the experimental data with predictions from an ambient noise model, the effects of the spectrum source level and propagation conditions are separated. It is found that wind speed influences noise levels more than the wave height does. Moreover, the contribution from the nearfield dominated the noise field at this site. They plot the source spectrum level of wind-generated noise for various wind speeds between 10 and 40 knots, in the frequency range 50 to 3200 Hz. This is one example of cooperation between modelling and measurement in the process of improving both.

4. CONCLUSIONS

4.1 Experiment

The experimental data available from shallow water provide information about the ambient noise level dependence on bottom type, total depth, sea-state and wind speed. Results of a few experiments on horizontal directionality have been published, both from acoustic arrays and ocean bottom mounted geophones. Most data confirm that ambient noise in shallow water is considerably more site-dependent than its counterpart in deep water, and that a knowledge of the propagation characteristics of the bottom is of prime importance in the prediction of noise levels at a particular site. In other words, characteristics of the ambient noise at one site cannot be generalized to other sites unless it is known their acoustic properties are the same.

The areas of research which most need experimental data are the ones using multisensor information, in conjunction with complete knowledge of propagation conditions at the sites. The lack of data is most noticeable with respect to the vertical directivity of shallow water ambient noise. Such ambient noise data are needed to validate and improve the numerous ambient noise models and to set the free parameters of the theories, such as the source-directivity parameter m for wind-generated noise (see Section 3). A study taking into account the influence of sensor depth and bottom types is very much needed.

As was demonstrated by Wilson, Wolf and Ingenito (1985) by their measurement of surf noise directivity, horizontal acoustic arrays can be used to isolate noise sources (see Section 2.3). Many more applications of this technique can be found. One can expect shipping and traffic noise to be highly directional in shallow water, as well as some forms of biological noise (e.g. whales). More use should be made of horizontal arrays to identify and study specific noise sources.

There still has not been any experiment on the influence of bottom currents on ambient noise in the ocean, mostly because of the experimental difficulties involved. Turbulence from oceanic currents was a factor which was strongly suspected as an important source of noise in several ambient measurements by ocean bottom-mounted hydrophones and geophones (Wenz, 1962; Bardyshev et al, 1971; Nichols 1981; Brocher and Iwatake, 1982; McGrath et al, 1977; Buck and Greene, 1980). A study of the correlation between current measurements and ambient noise data is needed to establish definitively whether there is a link.

The two hydrophone method advocated by Buck and Greene (1980) merits attention. For physically uncoupled hydrophones, as was their case, this method permits one to measure the true ambient noise power spectrum. If the use of the two hydrophone method was generalized for underwater ambient measurements, it would greatly help to resolve the controversy over the acoustic or non-acoustic nature of some of the infrasonic ambient noise.

4.2 Modelling

Acoustic environmental and propagation modelling, including summation of complex pressure at each hydrophone of an array, provides a very important insight into the effect of the existence of a waveguide on the array. General characteristics of the ambient noise at a particular site can now be predicted based on propagation data and wind speed. The simulation programs are at a stage where it is possible to test the response of different array configurations and signal processing to different environmental conditions. One can modify at will the geometry and weighting of the array, the position of the source, or the parameters of the environment. This allows one to test the response of the array under completely controlled conditions. It is also possible to separate the contributions from continuous and discrete modes, or from shipping and wind-generated noise, which is not possible with data from sea trials. This allows an inexpensive assessment of existing or new array design. The promising systems can then be put to the test in a real situation.

The main use of analytical models such as those developed by Buckingham (1980,1985) will be to place in perspective the important features of ambient noise in shallow water. This will be of help to interpret the numerical results from more general models run on computers.

Most of the environmental models discussed in Section 3 employ the shallow water attenuation model with rough boundaries developed by Kuperman and Ingenito (1977). However, this is a questionable choice when it is used to model wind-generated ambient noise. Their propagation model calculates only the coherent component of sound, corresponding only to the rays which underwent specular reflection. The coherent component represents the minimal magnitude of the signal, but the total acoustic energy arriving at the detector could conceivably be substantially larger than the calculation of the coherent part indicates. It therefore does not seem appropriate to use this propagation model in the case of ambient noise, when the quantity of interest is the total power arriving at the hydrophone. On the other hand, the unaccounted part of the acoustic energy is likely to become significant only when either or both of the boundaries present important roughness. Also, one must consider the subsequent propagation of the scattered energy: if it is scattered into higher-order, more highly attenuated modes, it may not contribute substantially to the resulting noise field.

Nonetheless, the use of simulation programs should become common place as a very useful tool in understanding and predicting ambient noise in shallow water, and subsequently in designing acoustic arrays and signal processing methods adapted to specific shallow water environments.

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FACTORY SOUND FIELDS - THEIR CHARACTERISTICS AND PREDICTION

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ABSTRACT

This paper presents the main results of completed and on-going research, mainly by the author and his colleagues, into factory sound fields. The important factors influencing the sound propagation and the reverberation time in factories are discussed. In particular, the obstacle effect resulting from the presence of fittings, and the influences of enclosure shape and construction, are elucidated. Methods for predicting factory sound fields are reviewed and evaluated.

SOMMAIRE

Cet article présente les résultats principaux de la recherche effectuée, surtout par cet auteur et ses collègues, sur les champs sonores en locaux industriels. Les importants facteurs qui influencent la propagation du son et le temps de rérverbération sont discutés. En particulier, l'effet d'obstacle qui résulte de la présence du contenu du local, et les influences de la forme et de la construction du local sont élucidés. Des méthodes pour la prévision des champs sonores sont revues et évaluées.

1. INTRODUCTION

The last decades have seen an increase of interest in, and need for, a better understanding of noise in factories and for accurate factory-noise prediction methods. This increase was stimulated by a greater awareness of the adverse effects of noise on man, and by increasingly stringent recommendations and regulations governing the noise exposure of factory workers. These were aimed at limiting hearing hazard resulting from worker-related aspect of factory noise; another factor, not dealt with in existing regulations, is that of the subjective satisfaction with the acoustic environment.

Noise in factories results from noisy machinery, processes and operations. Noise levels are enhanced by the confinement of the sound energy in the factory enclosure, resulting in the noise-exposure levels to which workers are subjected. In the case of impulsive noises, the enclosure also results in reverberance, caused by the finite rate of sound decay. Reverberance is believed to be related to the perceived worker satisfaction with the working environment, though this has yet to be proven or quantified. It is a common experience of the acoustic consultant that factory noise-reduction measures, even when little affecting noise-exposure levels, considerably improve the working environment by reducing reverberance.

An understanding of, and an ability accurately to predict, the sound field in a factory are essential for the estimation of probable worker noise exposure and satisfaction. They also allow the possibility of planning; that is, design of the factory enclosure, as well as noise source and worker-location layouts, in order to minimise noise exposure and annoyance. Further, in the case of existing factories, they permit evaluation of the efficacy and cost-effectiveness of enclosure noise-reduction measures.

Discussions with practitioners reveal that all too often, when they estimate noise levels or the efficacy of possible noise-reduction measures, the well-established Sabine theory, developed for auditoria, is applied. Unfortunately, for many factory spaces their application is invalid, as will be shown.

This paper presents some results of on-going research into factory sound fields, with emphasis on work carried out by the author and his collegues. This research has three main objectives:

1. To gain an understanding of the main factors influencing, and the characteristics of, factory sound fields;
2. To apply this knowledge to improve the factory acoustic environment;
3. To consolidate and evaluate methods for predicting factory sound fields.

A study of factory sound fields is a study of sound fields in enclosures with non-diffuse sound fields. However, factories are only one example of enclosures which have substantially non-diffuse sound fields. Thus the research results have relevance to other such enclosures - for example, corridors, open-plan offices and concert halls.

2. SOUND FIELD MEASURES

The sound field in a factory may usefully be characterised by two measures, one describing the steady-state spatial, and one the temporal, behaviour of the field. These are, respectively, the sound propagation (SP) and the reverberation time (RT). The SP is the variation of the sound pressure level (L_p) with distance, R, from an omnidirectional point source located at a position in the factory. SP is measured in octave bands or dB(A). The L_p can be normalised to the output sound power level (L_W) of the source; that is, SP(R) = L_p(R) - L_W in dB. SP prediction is of the utmost importance, being required for the prediction of the total noise level at a receiver position in the factory; the total level is the energy sum of the level contributions from the individual sources at the position, as given by the SP(R) and the source L_W's.

The RT is the usual room-acoustic measure, related to the rate of sound decay in the enclosure. It is normally measured in full or third-octave bands and is determined from the average of values measured at a number of source and receiver positions. The relevance of RT to factories is less obvious than is that of SP, and is a matter of some discussion among acousticians and consultants. As was mentioned above, it is likely that RT is related to the annoyance caused by impulsive sounds.

It is important to consider which frequencies are of interest in factories. Noise in factories may occur at all audio frequencies. However, the important measure for the prediction of noise-exposure levels is the A-weighted L_{eq}. Because of this weighting, low and high frequency factory noise usually, though by no means always, is of little importance. In this research frequencies corresponding to octave bands from 125Hz to 4kHz were investigated.

3. FACTORIES VS 'SABINE' SPACES

The theory of Sabine describes the spatial and temporal behaviour of sound in enclosures which are empty, which have all three dimensions similar, and in which the surface absorption is uniformly distributed. In such enclosures the pattern of sound reflection from the enclosure surfaces is such that at any position equal amounts of sound energy propagate in all directions - the sound field is diffuse. The theory predicts a steady-state sound field composed of two contributions, as shown in Figure 1 for the cases of low and high total absorption. Within a certain distance from a sound source (the so-called "reverberation radius") a "direct field" dominates. This is unaffected by the enclosure and has a level which decreases at a rate of −6dB per doubling of distance, due to spherical divergence. At larger distances, sound reflected from the enclosure dominates, resulting in a "reverberant field". Its level tends to decrease with volume and decreases with total absorption, but does not vary with source/receiver distance.

Regarding the temporal behaviour of the sound energy during sound decay, the level decays exponentially. The rate of decay is directly proportional to the factory volume to surface area ratio, and is inversely proportional to the total sound absorption, this being composed of surface absorption, as characterised by the diffuse-field absorption coefficient, and of air absorption.

Factories usually have mutually similar construction. The enclosure is erected over a floor of concrete and is supported by a portal frame system. The walls usually consist of glazing, masonry and/or cladding. The roof, sometimes singly or multiply pitched, or sawtooth, consists of insulated metal, asbestos and/or plasterboard panels which are mounted on purlins attached to the portal frames. Some factories have a flat, suspended inner ceiling. Of course factories may contain many fittings -machines, stock, workshops, services - distributed throughout the space and over its surfaces, especially the floor. Factory spaces differ from those described by the Sabine theory with respect to their contents, shape and surface absorption. Because of these differences the assumptions of the Sabine theory are not met. The factory sound field may be highly non-diffuse, the SP and RT characteristics of factories may not be a described above. Predictions using the classical theories may be highly inaccurate. This will be discussed in more detail below.

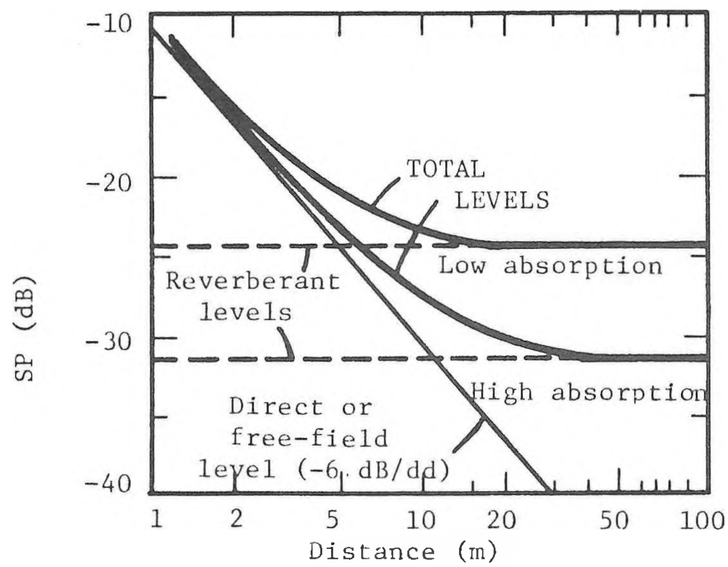


Figure 1. Direct, reverberant and total field SP's predicted by the Sabine theory for a large enclosure with low and high total absorption.

4. CHARACTERISTICS AND INFLUENCING FACTORS

In order to carry out the first of the above research objectives, theory based on the method of images approach (discussed below) was employed. RT and SP measurements were made in 45 factories of various sizes, shapes and constructions, when either or both nominally empty or fitted. A variable 1:50 scale factory-like model was used as a research tool. This consisted of a timber box with variable dimensions; absorbent materials and scattering objects could be introduced to model surface absorption and fittings. Full details of this work are published elsewhere [1,2,3].

What then are the main factors influencing factory SP and RT?

4.1 Fittings

A particularly important attribute of noisy factories is that they are fitted. Figure 2 shows the dB(A) SP measured along a diagonal of a factory when it was empty, partially fitted with 25 machines and fully fitted with 50 machines. Figure 3 shows the corresponding measured RT curves. The factory had average dimensions of $45m \times 40m \times 4m$, was of asbestos cladding construction and had a triply-pitched roof. The machines were metal-sheeting machines with typical dimensions of $2m \times 2m \times 1m$. Clearly the introduction of fittings decreased levels, especially at larger source distances, and the RT at all frequencies. The decreases were roughly proportional to the number of machines.

In a fitted factory - in fact, even in an unbounded region containing scatterers, sound propagates from the source to the receiver by an infinite number of paths as it "bounces between the fittings (and the walls, if present). Sound energy radiated from the source at a certain time arrives at the receiver continuously over a long period of time; there is reverberation even if there are no bounding surfaces. Further, the sound may strike the surfaces and arrive at the receiver from any direction. The presence of fittings in a factory causes a redistribution of sound energy, relative to the case of no fittings, towards the source due to backscattering. The fittings also increase the propagation losses in two ways. First, sound may be absorbed by the fittings. Secondly, and more importantly, the presence of fittings causes more sound to be scattered onto the bounding surfaces, effectively increasing their absorption. This 'apparent' absorption can be considerable - in fact many times greater than the fitting surface absorption. Further, the apparent absorption tends to be highest at frequencies at which the empty factory surface absorption is highest [4]. The effect of fitting scattering increases with the fitting volume density. Scale model studies have shown

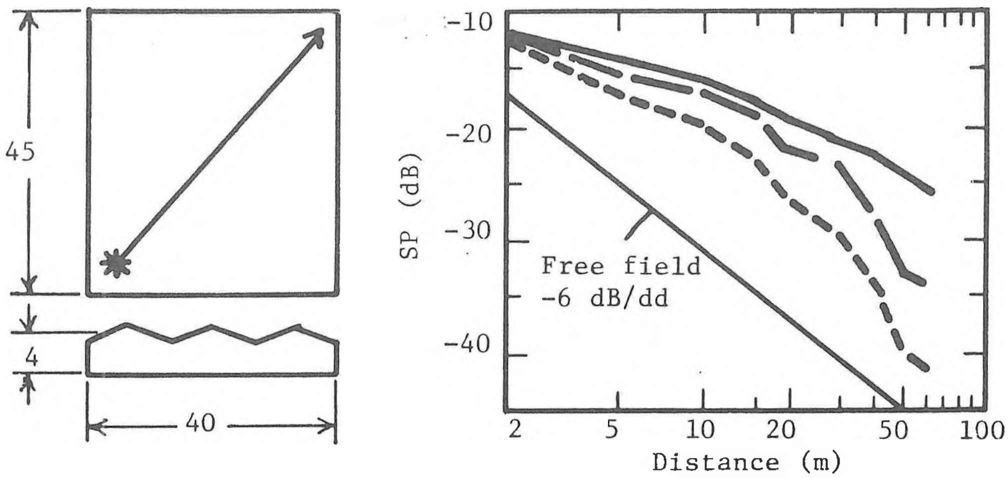


Figure 2. Measured dB(A) SP in the factory shown at left when empty (———) and fitted with 25 (— —) and 50 (- - - -) machines.

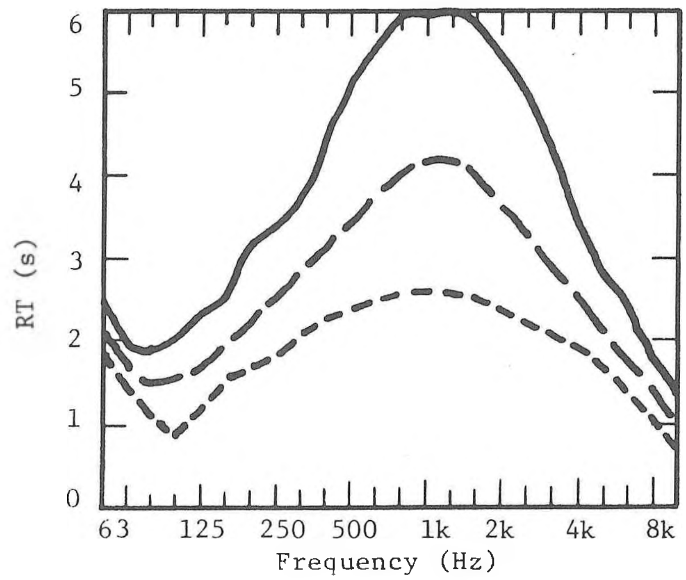


Figure 3. Measured third-octave band RT in factory shown in Fig. 2 when empty (———) and fitted with 25 (— —) or 50 (- - - -) machines.

that the SP and RT are approximately independent of the vertical distribution of the fittings 3; however if there is a large roof void sound may propagate in this 'empty' region, partially by-passing the fittings [5]. Further model experiments, using timber blocks of two different sizes as the fittings, suggest that fitting scattering depends on the fitting surface area. This is supported by full-scale measurements of the influence of fittings carried out by the INRS of France. They also showed that fitting orientation can be important [5]. Finally, as will be further discussed below, there is evidence that significant surface scattering occurs even in nominally-empty enclosures, presumably due to surface contouring.

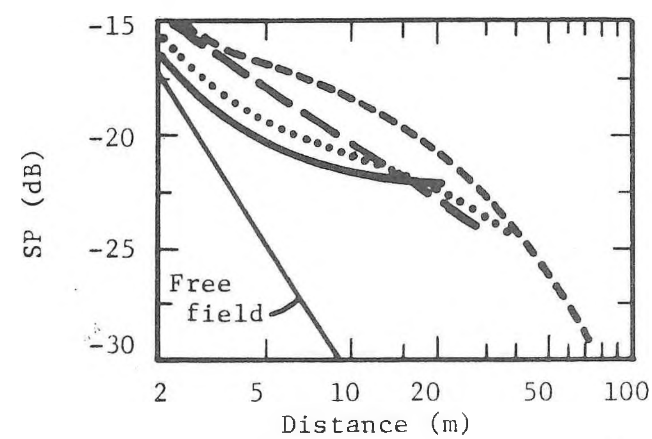
4.2 Enclosure shape – aspect ratio and volume

Clearly, factories have different shapes and sizes. They are usually large and disproportionate, with height much less than length and, often, width. Further, factories may have non-flat roofs; pitched or sawtooth roofs are not uncommon. More extremely, factories may be L- or T-shaped or have partial partitions which form coupled spaces. Here discussion is restricted to factories which are rectangular in plan shape and which have no partial partitions. Consideration of the surface reflection pattern shows that disproportionate shape or a non-flat roof results, at all positions, in a non-uniform angular distribution of the incident sound - that is, in a non-diffuse sound field.

The aspect ratio of the factory enclosure can significantly affect its SP characteristics. This is demonstrated in Figure 4 which shows the predicted SP curves for four moderately-densely-fitted enclosures of different shapes, but with the same surface areas. All have the same uniformly-distributed surface absorption and no air absorption; thus, the empty factories would all have the same Sabine reverberant-field level ($SP_{rev,empty} \simeq -20.5dB$). Clearly the SP curve shape varies considerably with aspect ratio. Only in the case of the cubic enclosure does a uniform reverberant level even approximately exist. In all other cases levels decrease monotonically with source/receiver distance. In general short-distance levels increase, and large-distance levels decrease, with increasing disproportionality.

The influence of aspect ratio on RT is complicated [1]. In truly empty, disproportionate enclosures the sound decay is expected to be non-exponential and the RT is difficult to determine; in any case the rate of decay varies with shape. In fitted factories the sound decay is expected to be substantially exponential and the RT decreases with aspect ratio. In practice sound decays measured even in highly disproportionate, nominally-empty factories tend to be more or less exponential. This must again be due to ambient surface scattering, and may imply that the effect of aspect ratio is less than expected.

The influence of volume changes on RT and SP are also complex [1]. Generally the RT increases with the enclosure volume to surface area ratio as predicted by the Sabine theory. Further, SP levels tend to decrease with increased volume. However the magnitudes of the changes which occur depend on the magnitude of the volume change and, in the case of SP, on which dimension is changed.



LINE	L : W : H	L	W	H
━━━━	1 : 1 : 1	25	25	25
••••••	5 :2.5: 1	48.4	24	10
▬ ▬	10 : 10: 1	40	40	9
— — —	10 : 1 : 1	95	9	9

Figure 4. Predicted SP in four fitted enclosures (details in table; dimensions in metres) with the same surface areas but different aspect ratios.

4.3 Enclosure shape - roof contour

In empty or uniformly fitted factories with flat roofs; the SP does not vary significantly with direction. However, roof contour results in directional SP variations, as illustrated in Figure 5. This figure shows the

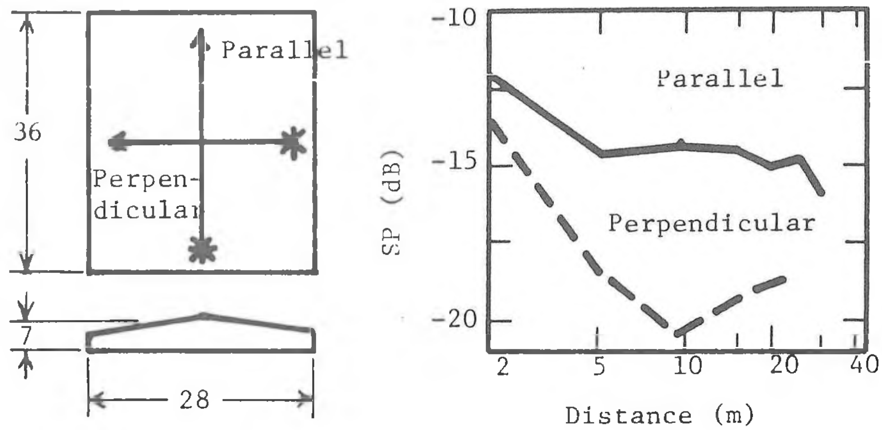


Figure 5. Measured 250Hz SP in two perpendicular directions in a factory with a singly-pitched roof.

250Hz SP measured along the two major axes in a factory with a singly-pitched roof as shown at left. Levels in the two directions differed by up to 6dB, and were lowest in the perpendicular direction. The differences were greatest at low frequency, decreased with frequency and were negligible above 500Hz. Similar measurements were made in a scale model with a flat, single-pitched or a triply-pitched roof [3]. In general levels were higher than flat-roof levels in directions parallel to the roof contours, and were lower in perpendicular directions. The effect was greatest with a singly-pitched roof, and decreased with roof height and fittings. The effects did not vary much with frequency. That this was contrary to the case of full-size factories suggests that the effects are not simply due to enclosure geometry, and require further study.

4.4 Surface absorption

Surface absorption strongly affects factory sound fields. All factory enclosures have a certain amount of ambient surface absorption which depends on the factory construction. The absorption of concrete and brick or blockwork is small, and increases with frequency. On the other hand panel roofs, suspended ceilings and glazing, for example, may have considerable effective absorption at low or middle frequencies owing to their acoustically-induced, vibration-response characteristics [6]. Since the RT is inversely related to the total (surface plus air) absorption in an enclosure, much can be learned about the ambient absorption by looking at the shapes and magnitudes of measured factory RT spectra - see, for example, Figure 3. In fact, similar information is provided by the frequency variation of the large-distance SP levels. Figure 6 shows the estimated absorption coefficient of two common roof constructions, as estimated from measured empty-factory RTs. The constructions are:

- TYPE A - Double panel construction. The outer panel is of corrugated asbestos; the inner panel is of flat asbestos or plaster-board. The panels may be separated by battens and the resulting space may contain insulation. This construction is typical of older British factories;
- TYPE B - Steel-deck, consisting of an interior corrugated-steel panel with insulation, asphault and gravel above. This construction is typical of North American factories and of some new British factories.

It should be mentioned that there is evidence that the effective absorption of some newer, light-weight constructions, consisting of a metal/solid-foam sandwich, occurs at the more subjectively-important mid-frequencies. There is also evidence that in certain cases the angular variation of the effective absorption of factory roofs may significantly influence the sound field [7].

4.5 Characteristics

Figure 2 well demonstrates the general characteristics of empty and fitted factory SP curves. All three curves

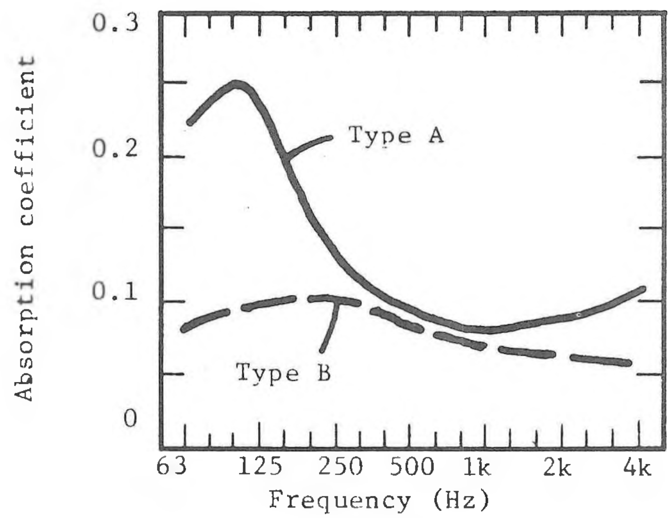


Figure 6. Estimated effective absorption coefficient of two common factory roof constructions: Type A - double asbestos panel; Type B - steel deck.

approach the free-field SP curve at short distances. However, levels at 1 or 2m from the source may be several decibels above free-field levels at all frequencies. That is, the enclosure and fittings can significantly influence operator positions, contrary to common belief. In empty factories the SP curve slope remains approximately constant, or decreases with frequency; in fitted factories the slope tends to increase with distance. In the case of dense fitting the SP curve may cross the free-field line at large distances.

5. CONTROL OF FACTORY NOISE

The aim of factory noise control is to improve the work environment by the reduction of noise-exposure levels and of reverberation. This may be done either at the design stage, or after the factory is built. As mentioned, the important quantity for the prediction of noise-exposure levels in a factory containing many noise sources is the sound pressure level at positions throughout the factory. The L_p at position R is the energy sum of the level contributions from each source at R, as determined from SP(R).

Clearly, the more specific objective of noise control is to minimise the RT, and the SP in the appropriate source/receiver distance range. At the design stage the factory shape and construction can be optimised. After construction, the RT can be reduced by increasing the total propagation losses. SP levels at short and large distances are reduced by increasing propagation losses and by reducing and increasing respectively, the redistribution of sound energy due to fittings. Table 1 shows some factory-acoustic parameters which can be modified in order to reduce the SP and RT in fitted factories, and the changes required.

Several further comments are necessary in relation to these results. First the distance which delimits the short and large-distance region is typically 10 – 20m. Also, the short-distance region can extend to as close as 1 – 2m from a point source and, therefore, may include operator positions. Secondly, it is clear from Table 1 that the changes of some parameters, required to reduce the SP and the RT, are often in conflict. The same is true with respect to simultaneous reduction of short and large-distance SP levels. If, for example, it is required to reduce all variables, then the only feasible measure is to increase the surface and fitting absorptions. Measures only causing an energy redistribution are inapplicable. Thirdly, it should be noted that, in many factories, it is not possible to modify the floor, side and end-wall absorption.

Because the presence of scatterers increases the effective surface absorption, a combination of scatterers and surface absorption may be especially effective for the reduction of large-distance levels and of the RT. More

TABLE 1

Changes of factory-acoustic parameters which reduce
the SP and RT in empty and fitted factories
(↑ increase, ↓ decrease)

Parameter	SP (short)	SP (large)	RT
Width:height ratio	↑	↓	↑
Height	↑	↓	↓
Surface absorption and distribution	↑ on surfaces nearest the source	↑	↑
Fitting density	↓	↑	↑
Fitting absorption	↑	↑	↑

generally, since the factory ceiling is often a low-frequency absorber, low-frequency scatterers, which are mid and/or high frequency absorbers, may be a particularly cost-effective treatment. A further reduction of large-distance levels may be achieved if scatterers are located in the roof void, blocking the propagation path which may short-circuit the lower fitted region. A possible application of these principles is the use of solid acoustic baffles, hanging at random locations throughout the roof void. A second possibility is the use of scatterer/absorbers of inverted pyramidial shape, suspended above individual noise sources. The scatterers should have dimensions of at least 2m to provide adequate low-frequency scattering. Their surfaces should be covered with porous absorbent to provide mid and high-frequency absorption.

One important observation, relevant to factory design, must be made about factory height. It normally is expected that decreasing the height increases noise-exposure levels by increasing the sound energy density; this is the case in empty factories. However, as discussed above, decreasing the height of fitted factories also increases the fitting volume density and causes a redistribution of sound energy, tending to decrease large-distance SP levels. In some cases this may result in decreased noise-exposure levels, contrary to expectation. An example of this is discussed in [7]. Of course, decreasing the height also reduces the RT.

Finally, a non-flat roof can, in principle, be used to reduce large-distance SP levels in certain directions. Source and receiver locations should be laid out so as to maximise source/receiver distances and the beneficial effects of non-flat roofs.

6. PREDICTION OF FACTORY SP AND RT

What tools are available for the prediction of factory SP? It has been established that the Sabine theory is not generally applicable. There are three main practicable alternatives: physical scale models, empirical formulae and geometric-acoustic models.

6.1 Physical scale modelling

Scale modelling has the obvious advantage that, in principle, any factory configuration can be modelled. The feasibility of factory scale modelling has been demonstrated by successfully modelling an existing factory at 1:16 scale [8]. The factory, which produced light-bulbs, had average dimensions of $120m \times 45m \times 9m$ and was of typical construction with a singly-pitched roof of asbestos-panel cladding. The walls and floor of the model were constructed of varnished timber and plastic. The roof construction was based on a distributed Helmholtz-resonator principle. The fittings were timber and cardboard blocks and tin cans of the approximate sizes and shapes of the main factory fittings. Figure 7 shows the RT measured in the full-size and scale-model factories. The agreement is generally within 10%. Figure 8 shows the corresponding dB(A) SP results. The accuracy of modelling averaged 0.5dB(A); that in the individual octave bands averaged 1.5dB. This 1:16 scale model has also been used to investigate the performance of two conventional noise-reduction techniques - functional absorbers and barriers [8].

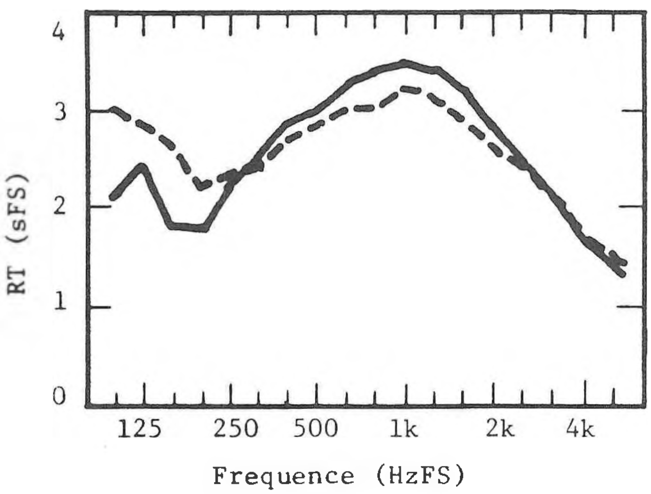


Figure 7. Measured third-octave band RT in a full-size factory (———) and in its 1:16 scale model (– – –).

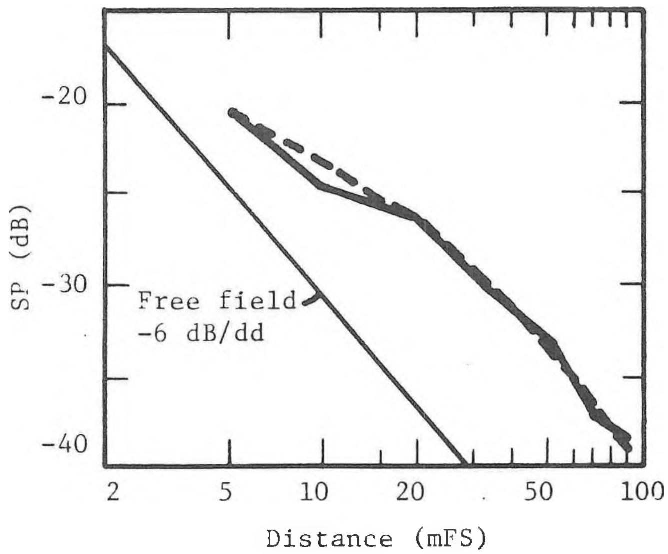


Figure 8. As Fig. 7 but for the measured dB(A) SP.

Clearly, if scale models are to be used as design aids, which must be cost-effective, small scales must be chosen. Unfortunately, research aimed at evaluating factory scale modelling at 1:50 scale [2,3] has shown the accuracy to be unacceptably low for several reasons. First, scale models have an upper limit for accurate scaling of air absorption. For 1dB accuracy this is about 2.5kHzFS (FS = full scale) at 1:16 scale, but only 800HzFS at 1:50 scale. An 800HzFS limit makes the accurate determination of dB(A) levels impossible. Secondly, the non-omnidirectional response of even the smallest available microphones at the high model test frequencies significantly influences the SP measured in disproportionate, non-diffuse-field factory models. Thirdly, the absorption coefficient of varnished timber, the most convenient material for modelling acoustically-hard factory surfaces, is in some cases too absorbent.

6.2 Empirical formulae

Empirical formulae derived from factory measurements, such as those developed by Friberg [9], have the advantages of ease and speed of use. Their disadvantages are, of course, reduced accuracy and lack of sensitivity to parameter changes. The Friberg formulae are inaccurate in assuming the SP curve to be of single, constant slope (see Figure 2). Further, they disregard the absolute level of the SP curve and provide limited frequency information. Work is in process to develop more comprehensive empirical formulae [10].

6.3 Geometric-acoustics theory

Geometric-acoustics models are based on a high-frequency approximation and may not be accurate at low frequencies. Ray-tracing methods have been applied to factories with some success [11]. They have the advantage of being able to deal with irregular factory configurations, and to include individual barriers and surface scattering.

An alternative approach is that of the method of images. Its application to empty, parallelepipedic enclosures is well known [12,13]. Borish [14] has extended the method to arbitrary polyhedra. L'Espérance et al. [15] have incorporated barriers into an SP prediction. Jovicic [16] and Lindqvist [17] among others, have extended the image method to the prediction of SP in enclosures containing isotropically-distributed fittings. The Jovicic theory has been extended by this author [1]. According to these theories the fittings are quantified by their average scattering cross-section density, Q in m^{-1}. Lemire and Nicolas [18] suggested a simpler way to account for fittings - the image energy is exponentially attenuated as the sound propagates through fitted regions.

Efforts have been made to evaluate the applicability of the extended Jovicic theory as a prediction tool. This has been accomplished by comparing predictions with the results of measurements made in the variable scale model and in full-size factories [19]. It is clear that the theory qualitatively describes many observed factory-acoustic characteristics, such as the influences of enclosure shape, surface absorption and fittings. However, its accuracy is limited by not incorporating the influence of roof contour or non-uniform horizontal-plane fitting distributions.

Quantitative evaluation has proved more difficult. A problem common to the use of any prediction theory (and often not sufficiently considered) is that of the accurate determination of the parameter values. In the case of factories what, for example, is the effective absorption of a given factory cladding? What is the scattering cross-section density of a given factory's fittings? In principle, the parameter values for the simplified factory scale model are readily established. In practice this has not always been found to be the case. For example, in certain cases the changes of SP and RT which occurred in the model when porous surface absorption was introduced in no way correlated with the measured diffuse-field absorption of the material [3].

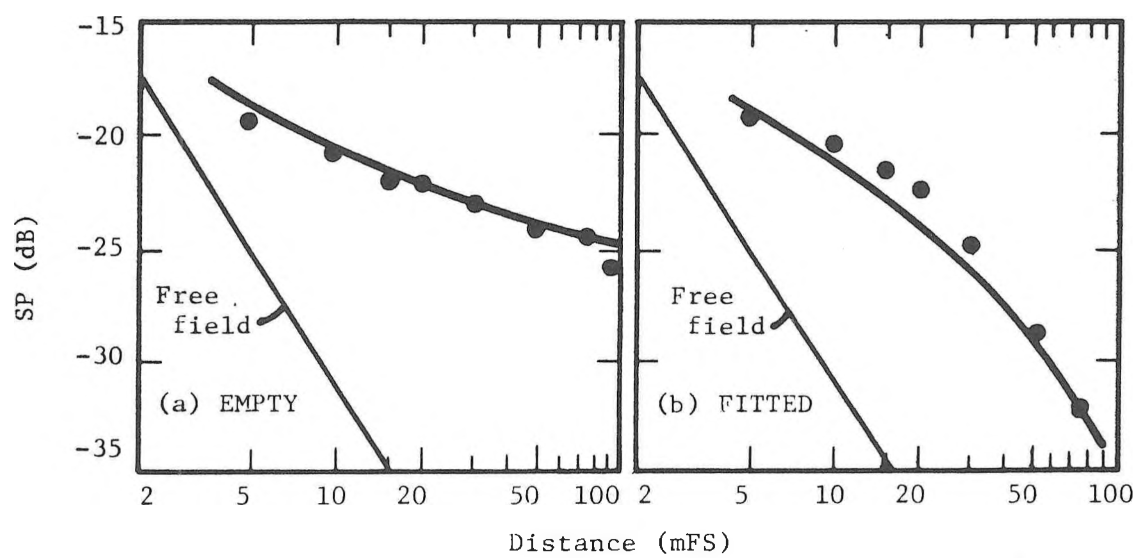


Figure 9. Measured (● ●) and predicted (———) 315HzFS SP in a 1:50 scale model when empty and fitted.

In any case, Figure 9 shows the 315HzFS SP measured in the variable 1:50 scale model with dimensions $110m$FS$\times 55m$FS and $5.5m$FS and varnished plywood surfaces, when empty, and when fitted with 220 varnished timber cubes with 2.2mFS side length (Jovicic scattering cross-section density, Q = $0.05m$FS^{-1}).

Also shown are the curves predicted by the extended Jovicic theory using the relevant air absorption exponent ($m = 0.0005Np/m$), the measured diffuse-field absorption coefficient of varnished timber ($\alpha = 0.065$), and $Q = 0.05mFS^{-1}$. Clearly the agreement is excellent, within 1.5dB, in both cases and at all source/receiver distances. In other frequency bands and shape configurations the agreement was equally good. In general the results suggest that the theory fairly accurately models the influence of shape, surface absorption and fittings - at least in the case of a simple scale model.

Comparisons have also been made between predicted and measured SP's for 30 empty factories [20]. This was first done using Q = 0 and the known prediction parameter (e.g. dimensions, air absorption) values, but varying the value of the unknown parameter (the surface-absorption coefficient) to see if a satisfactory best-fit could be obtained. This has led to several conclusions:

a) Most nominally-empty factories show SP characteristics associated with fitted factories. As mentioned above, this is presumably due to ambient surface scattering.

b) In most cases predictions made using the absorption coefficient obtained from the measured RT using the Eyring theory gave agreement with measurement within 1dB at source/receiver distances less than about 20m, but overestimated the SP at larger distances.

c) In most cases agreement within 1dB could be obtained using an appropriate non-zero Q value.

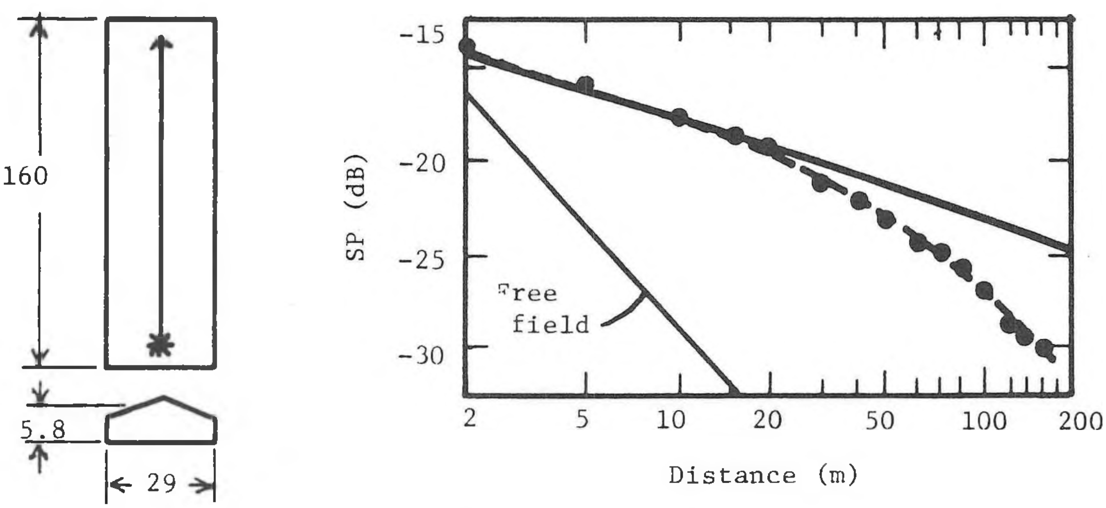


Figure 10. Measured (•) and predicted (——— $Q = 0m^{-1}$; — — $Q = 0.03m^{-1}$) SP at 1kHz in an empty factory as shown at left.

An extreme case of a nominally-empty factory with dimensions of $160m \times 29m \times 5.8m$ is shown in Figure 10. It has also been found that the average absorption coefficient, calculated as above, does not vary much in factories with the same roof construction [20]. For the case of 11 factories with Type A roofs and 5 with Type B roofs, predictions made for the 1kHz octave band using the average calculated absorption coefficient and $Q = 0.03m^{-1}$ gave an average agreement with measured levels of at worst 1.5dB. Use of the absorption coefficient predicted the 1kHz RT to within 0.2s (0.5%) on average. The above procedure is now being extended to factories in which the SP was measured when the factory was empty and fitted. It is hoped to be able to generalise the results and correlate the best-fit Q values with known details of the factory fittings. This should establish an accurate and proven method for predicting SP and RT in empty and fitted factories.

7. CONCLUSION

Research carried out to date has led to a better understanding of the characteristics of, and factors influencing, factory sound propagation and reverberation time. In particular, the influence of factory fittings and roof contour have been elucidated. This understanding has been applied to establish the basic principles and methods for noise control. Important information about the effective absorption of factory surfaces and the scattering cross-section density of factory fittings is being inferred from measurement results; however further research on the estimation and measurement of these quantities is necessary. Scale-modelling techniques applied to factories have been found to be accurate at 1:16 scale; however, the accuracy becomes unacceptably low at the more cost-effective 1:50 scale. Empirical formulae and ray-tracing methods have been used to predict factory sound fields with varied success. An extended Jovicic geometric-acoustic /method-of-images theory has been shown to describe many observed factory-acoustic effects. Comparisons of predictions with results of SP measurements in empty and fitted factories are leading towards the consolidation of a reliable and accurate factory SP prediction method.

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ÉTUDE EXPLORATOIRE DE L'EFFET DU CONTENU SPECTRAL DES BRUITS IMPULSIONNELS SUR L'ACQUISITION DE LA FATIGUE AUDITIVE
PRELIMINARY STUDY OF THE EFFECT OF THE SPECTRAL CONTENT OF IMPULSIVE NOISES ON THE ACQUISITION OF AUDITORY FATIGUE

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SOMMAIRE

Grâce au développement d'un système de génération de signaux impulsionnels contrôlés par ordinateur il est maintenant possible d'évaluer la contribution du contenu spectral des impulsions sonores par des mesures de fatigue auditive (DTS: décalage temporaire des seuils auditifs). Pour ce faire, il a fallu mettre au point une méthodologie pour obtenir, en un minimum de temps, un effet asymptotique d'une ampleur pré-déterminée. Cette méthodologie a été développée et mise à l'essai pour trois signaux impulsionnels de contenus spectraux différents s'étendant pour le signal A de 300 à 1000 Hz, de 300 à 3000 Hz pour le signal B et de 300 à 4000 Hz pour le signal C. Les courbes d'acquisition de la fatigue auditive démontraient qu'un DTS asymptotique de l'ordre de 10 dB était atteint après environ 30 minutes d'exposition. Pour obtenir ce même effet, le niveau de pression de crête du signal B et C devait être de 10 à 12 dB inférieur à celui du signal A. Ainsi, le contenu spectral semble un paramètre important à considérer dans l'élaboration de critères de nocivité des bruits impulsionnels.

SUMMARY

With the development of a computerized impulsive noise generator, it has become possible to study the effect of the spectral content of impulsive noises by mesuring temporary threshold shift (TTS). To conduct this type of study, a new methodology had to be developed for obtaining a target amount of asymptotic threshold shift in a minimum exposure time. This methodology has been tested with three impulse signals of different frequency bandwidths: signal A extending from 300 to 1000 Hz, signal B from 300 to 3000 Hz and signal C from 300 to 4000 Hz. The TTS growth curves reach an asymptote of about 10 dB after an exposure time of approximately 30 minutes. To obtain this effect, the peak level of signals B and C had to be 0 to 12 dB below that of signal A. Thus, it appears that the spectral content is a very important parameter in the prediction of damage risks to hearing from impulsive noise.

PROBLEMATIQUE
INTRODUCTION

Les critères de nocivité des bruits impulsionnels publiés à ce jour [1,2,3,4] sont définis en fonction de paramètres du bruit facilement mesurables soient la pression de crête, le nombre d'impulsions et le temps de décroissance. Ce n'est que très récemment que le contenu spectral de ce type de bruit a été considéré [5], car ce paramètre était difficile à contrôler par les techniques de génération de signaux impulsionnels utilisées jusqu'à maintenant. A l'aide d'un nouveau dispositif de génération de signaux sonores par ordinateur [6,7], nous avons pu étudier l'importance de l'effet du contenu spectral de bruits de courtes durées (1 à 3 msec) sur l'acquisition de la fatigue auditive.

ÉTAT DE LA QUESTION
STATE OF THE ART

Pour tenter d'établir la nocivité des bruits impulsionnels, les chercheurs recourent à trois types de méthodologies: des études épidémiologiques de DPS (décalage permanent des seuils d'audition), des études histologiques et morphologiques chez l'animal et des études expérimentales de DTS (décalage temporaire des seuils d'audition) chez des sujets humains. Chacun de ces types d'études comporte des contraintes.

La première de ces approches comporte de sérieuses limites; il s'agit de procéder par études rétrospectives d'un grand nombre de personnes dont l'état de l'audition représenterait des échantillons homogènes reflétant l'effet d'un seul paramètre donné des bruits impulsionnels. Ceci est impossible à envisager dans le contexte d'un milieu de travail où la contribution relative de chaque paramètre et l'interaction entre ces paramètres sont difficiles à isoler.

Dans ce contexte, le recours à un modèle animal [8,9,10,11] présente un très grand intérêt. Ainsi, des études ont démontré que, dans certains cas du moins, les dommages produits par les bruits impulsionnels sont supérieurs à ceux attendus pour une quantité égale d'énergie de bruits continus. Ces résultats sont essentiels pour comprendre le mécanisme lésionnel. Toutefois, ils ne sont qu'indirectement applicables à l'homme. Il est certes nécessaire de connaître la réponse spécifique de l'oreille humaine et d'identifier un point d'ancrage entre cette réponse et les observations faites sur l'animal.

Ces objectifs peuvent vraisemblablement être atteints par l'étude de DAS (décalage asymptotique des seuils d'audition). En effet, le DAS représenterait un point d'ancrage permettant de comparer les études entre elles [12]. Ce type de comparaisons est possible puisque:

1) un bruit donné engendre un effet donné dont la valeur est stable, <u>i.e.</u> indépendante du temps d'exposition [13];

2) la durée du maintien à l'asymptote influence le processus de récupération [14];

3) les deux informations précédentes (DAS et récupération) sont

vraisemblablement liées à la nocivité du bruit en terme de dommages permanents à l'audition [12];

4) au plan physio-pathologique, le DAS permet de mettre en relation la perte d'audition permanente et l'importance des lésions relevées sur les cohlées animales [15,16].

Ainsi, l'étude des DAS permettrait d'associer une ampleur donnée de déficit auditif temporaire à un risque donné de lésion. Si cette valeur stable est obtenue par études d'équinocivité, il devient possible de s'affranchir des problèmes de conversion DTS-paramètres du bruit. Ces problèmes se situent principalement au niveau de l'équivalence des effets en termes de risques d'atteinte à l'audition (ampleur et temps d'acquisition):

a) Ampleur de DTS et risque
Magnitude of DTS and risk

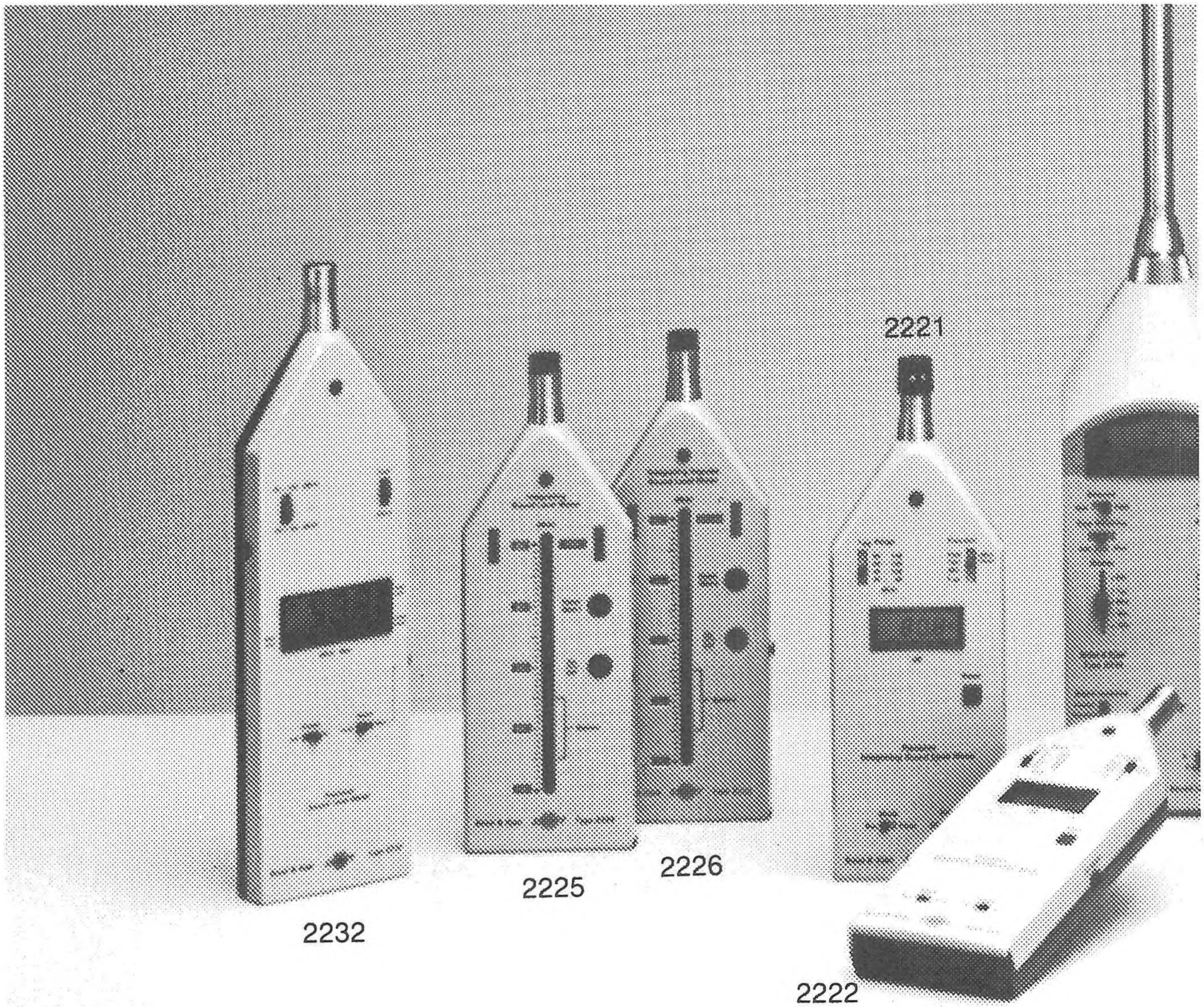
On ne peut convertir des valeurs de DTS en valeurs correspondantes de la variation du paramètre physique du bruit. Par exemple, on ne peut affirmer qu'un bruit A engendrant un DTS de 6 dB est deux fois moins nocifs qu'un bruit B provoquant l'acquisition d'un DTS de 12 dB. Il s'agit donc d'obtenir un indice fiable qui soit prédicteur de la sensibilité de l'oreille aux paramètres du bruit; ceci peut se traduire par la recherche de l'équinocivité des bruits, i.e. la recherche d'un iso-effet (ou effet constant) en fonction de la variation du paramètre étudié.

b) Temps d'acquisition et risque
Time of acquisition and risk

La signification d'une valeur donnée de DTS dépend de la façon dont il a été acquis dans le temps [14,17]. Par exemple, deux bruits différents A et B peuvent induire une même quantité de DTS, soit 9 dB, mais après des temps d'exposition de 10 et de 20 minutes respectivement. Dans ce cas, on peut difficilement convertir le temps en valeur correspondante de nocivité.

Il est donc préférable d'associer une valeur stable à une exposition donnée. Ceci peut être réalisé en obtenant des courbes d'acquisition de la fatigue auditive, lesquelles tendent vers une asymptote. Celle-ci peut être limitée à 10 dB de DTS de façon à émerger de l'erreur de mesure tout en limitant l'ampleur du DTS pour le sujet exposé.

L'évaluation de l'équinocivité par la mesure du DAS représente une approche nouvelle de l'étude du DTS causé par les bruits impulsionnels [16]. Toutefois, dans le cas des bruits de courte durée unitaire (type détonation d'armes à feu), il reste à déterminer la faisabilité d'une telle étude. En fait, deux questions se posent: a) quelle est la durée d'exposition à une cadence donnée qui engendre un DAS? et b) comment obtenir un DAS cible associé à l'iso-effet recherché?



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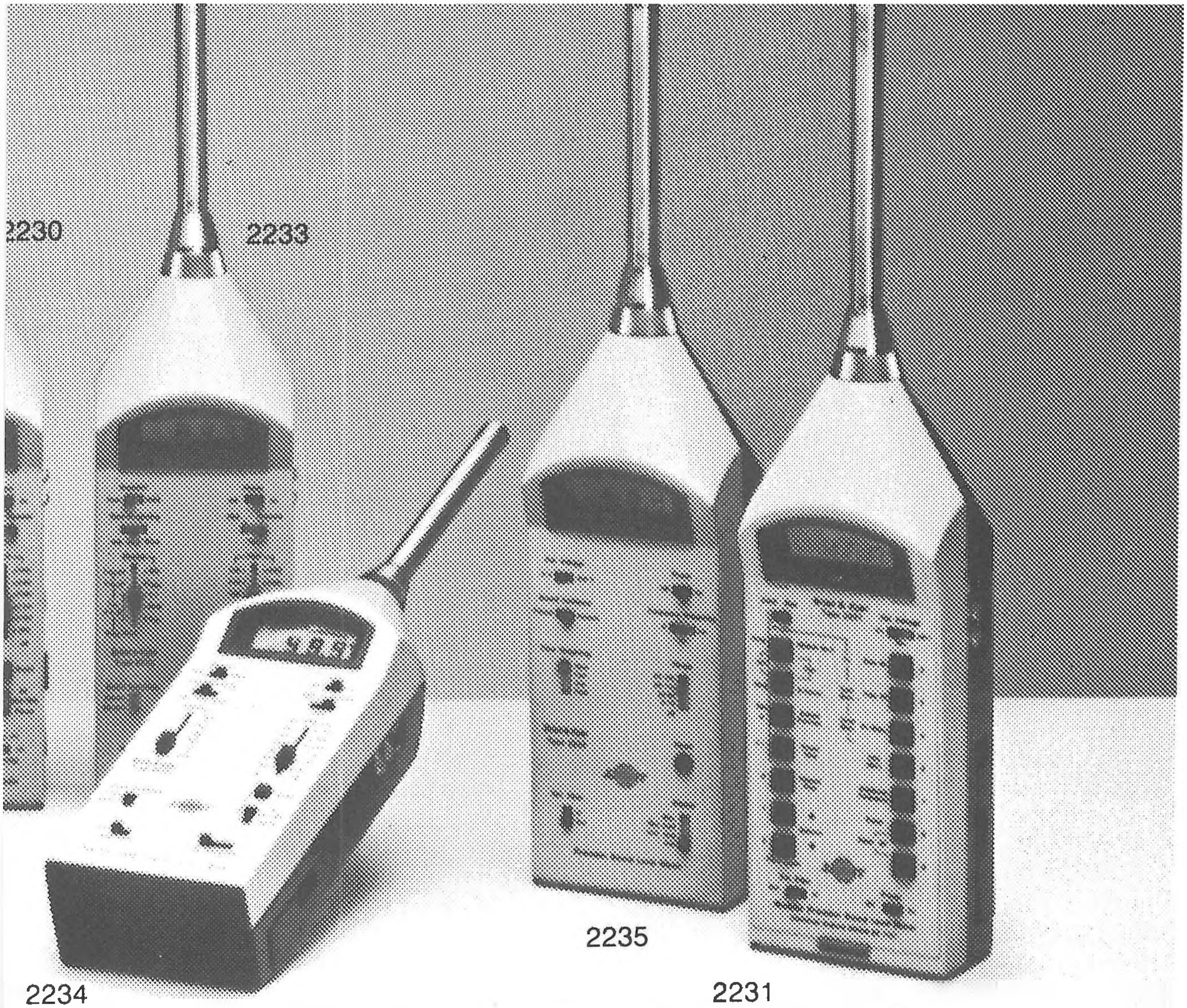
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BUT DE L'ÉTUDE
OBJECTIVE OF THE STUDY

La présente recherche avait un caractère exploratoire. Elle visait à apporter des éléments de réponses aux questions relatives à la faisabilité d'études, chez l'humain, du DAS produit par des signaux impulsionnels de courte durée unitaire. Il s'agissait donc de développer une méthodologie nouvelle.

MÉTHODOLOGIE
METHODOLOGY

Approche expérimentale
Experimental approach

L'étude du DAS comportait deux types de contraintes: a) les limites liées à l'ampleur du DTS et b) la durée d'exposition.

a) Limites liées à l'ampleur du DTS
Limits related to the DTS amplitude

L'ampleur du DTS ne devait pas dépasser 15 dB à l'oreille et à la fréquence la plus sensible pour éviter toute atteinte auditive permanente. Il a été démontré, dans plusieurs études antérieures [19,20,21,22], qu'un tel niveau de DTS est toujours complètement récupéré. De plus, cette quantité de DTS est compatible avec plusieurs activités de la vie courante (ex.: 15 minutes dans une discothèque, 30 minutes de circulation en motocyclette, ou 2 heures en automobile fenêtre ouverte sur une autoroute). L'ampleur de DTS admissible devait toutefois être supérieure à la marge d'erreur de mesure audiométrique, i.e. 5 dB [23,24]. Ces limites minimales et maximales de DTS exigeaient une progression des expositions et l'arrêt de celles-ci lorsqu'un DTS de 15 dB était atteint.

b) Durée d'exposition
Duration of exposure

L'objectif était d'obtenir une valeur asymptotique de décalage des seuils d'audition observable après des temps d'exposition éventuellement longs. Il fallait toutefois tenir compte du fait que, pour certains signaux riches en basses fréquences, le sujet pouvait rapidement ressentir une gêne, même à des niveaux crêtes relativement faibles. D'après une récente étude [18] portant sur l'acquisition de la fatigue auditive causée par l'exposition à des bruits d'impact, une durée de 20 à 30 minutes pouvait suffire pour atteindre l'asymptote à une cadence de 1 impact/sec; il s'agit de durées supérieures à celles utilisées dans plusieurs études antérieures (2 à 4 minutes, par exemple) [25,26,27,28].

Ainsi, nous avons voulu comparer l'effet d'un type de bruit par rapport à un autre en recherchant la variation d'un paramètre permettant d'obtenir un même effet, le paramètre retenu étant le niveau de pression de crête. Cet iso-effet a été fixé à une valeur de DTS (éventuellement de DAS) comprise entre 8 et 12 dB après une exposition de 24 minutes.

Sujets
Subjects

L'expérimentation ayant un caractère exploratoire et méthodologique, il a été convenu d'étudier un nombre élevé d'expositions auprès d'un nombre restreint de sujets normaux. Trois sujets (1 femme et 2 hommes) ont participé à la recherche. Ceux-ci devaient rencontrer les critères suivants:

1- présenter un seuil tonal aérien inférieur à 15 dB HL (réf. ANSI S3.6-1969) [29] à chacune des oreilles, aux fréquences audiométriques de 500 à 6000 Hz,
2- présenter des tympanogrammes normaux (valeur maximale de pression de l'oreille moyenne entre -100 et +50 mm H_2O et compliance statique entre 0,3 et 2 mmhos) [30],
3- ne présenter aucune histoire de maladies ayant pu affecter le système auditif.

Production des signaux impulsionnels
Production of the impulsive signals

La génération des signaux transitoires à paramètres contrôlés a nécessité le développement d'un système spécial [6,7]. Le signal est généré numériquement sur ordinateur pour être ensuite converti analogiquement avant d'être envoyé dans une chaîne électro-acoustique. Les principes théoriques de la génération et du contrôle systématique par boucle de retour seront présentés dans un article en cours de rédaction [31].

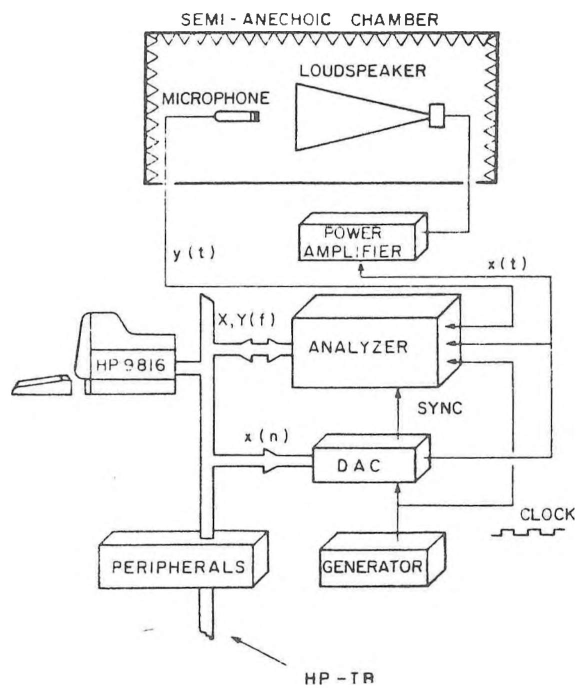


Figure 1 - Schéma du dispositif expérimental (tiré de Sawan et al., 1985)
Diagram of experimental apparatus

La figure 1 illustre le schéma du dispositif expérimental. Le calculateur (HP 9816) synthétise le signal numérique. Après conversion analogique, le signal est injecté à l'entrée de la chaîne acoustique (un amplificateur BGW Systems, Model 750A et un haut-parleur); un atténuateur (HP 350D) permet de contrôler le gain à la sortie. Un microphone recueille le signal émis, le dirige à l'analyseur FFT (BK 2032) qui effectue les calculs nécessaires pour produire le signal modifié.

La figure 2 illustre la qualité du signal contrôlé. Le signal désiré se compare très bien au signal obtenu après correction par la fonction de transfert inverse de la chaîne électro-acoustique.

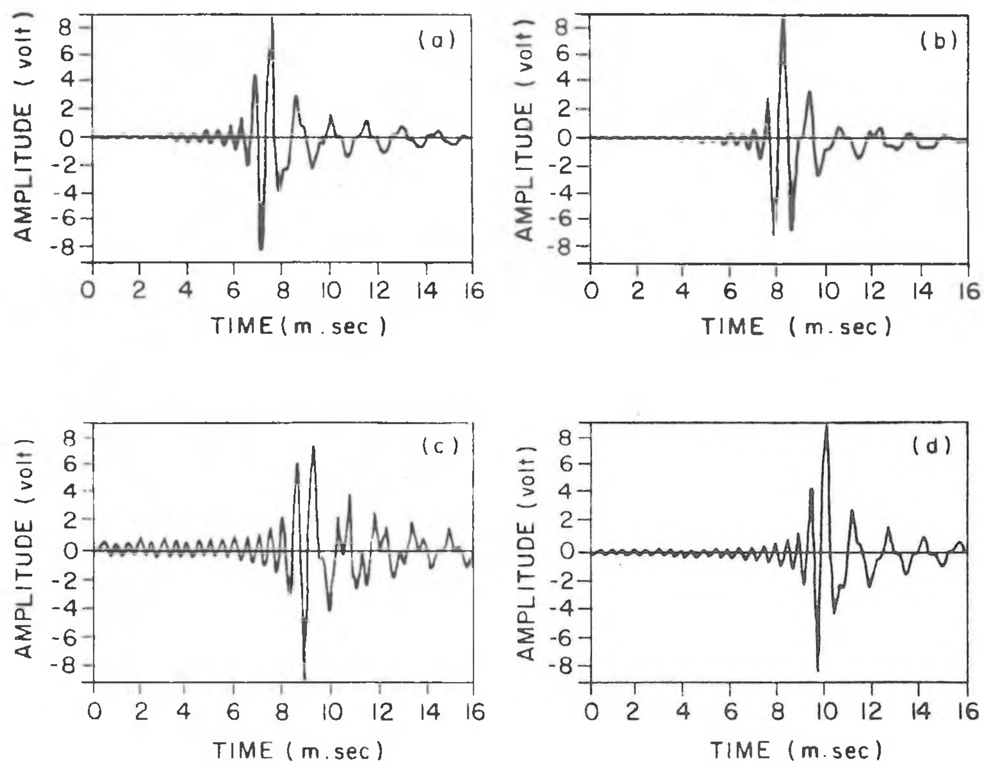


Figure 2. Fonctions temporelles
(a) Numérique
(b) Obtenue
(c) Corrigée
(d) Réelle

Time functions
(a) Digitally generated
(b) Obtained
(c) Corrected input
(d) Actual output

La figure 3 témoigne du contrôle sur le contenu fréquentiel. On remarquera la versatilité du système qui permet de contrôler un signal aussi bien en bande à longueur constante (3b) qu'en bande à pourcentage constant (1/3 octave, 3c).

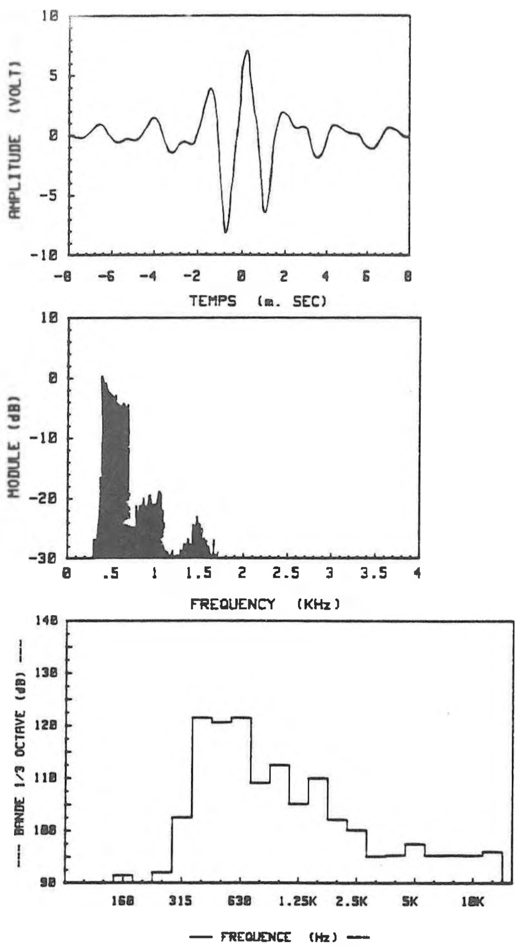


Figure 3. Informations sur le signal
(a) Temps
(b) Bande étroite
(c) Bande 1/3 d'octave

Informations on the signal
(a) Time
(b) Narrow band
(c) Third octave

Choix des signaux
Choice of signals

L'étude portait sur des signaux impulsionnels de courte durée en référence à des signaux de type armes à feu émis en champ libre; c'est ce type de signaux qui a été le plus étudié à ce jour [1,27,32]. Les signaux devaient avoir un contenu spectral varié. Ceci pouvait être obtenu au moyen d'un signal numérique de type (sin x)/x [6,7] dont on varie la bande passante. Les repères suivants ont guidé le choix des signaux.

1- une courbe théorique d'iso-nocivité fondée sur la fonction de transfert de l'oreille moyenne et externe affichant une atténuation de -6 dB/octave en basses fréquences et de +18 dB/octave en hautes fréquence avec une sensibilité maximale à 3000 Hz [5],

2- les limites du système actuel en phase de développement: le contrôle du contenu fréquentiel était limité en basses fréquences à 300 Hz et en hautes fréquences à 5000 Hz. Le Lp ne pouvait dépasser 135-140 dB, de façon à conserver une gamme dynamique d'au moins 20 dB à la fréquence supérieure de coupure du signal, 3- la recherche d'un DTS cible d'environ 10 dB et une limite de DTS admissible de 15 dB.

Ainsi, trois signaux de largeurs de bande différentes mais dont la fréquence inférieure de coupure était la même ont été retenus. Au tableau 1, sont inscrites les valeurs des paramètres des 3 signaux utilisés pour l'étude. Le $L\hat{p}$ maximal variait de 135 à 140 dB, le contenu spectral s'étendait de 0,3 à 1 kHz pour le signal A, de 0,3 à 3 kHz pour le signal B et de 0,3 à 4 kHz pour le signal C, les temps de montée et de décroissance étaient symétriques et passaient de 0,34 à 0,12 msec; la cadence était de 1 impulsion/sec. A titre d'illustration, la figure 2 reproduit a) l'allure temporelle, b) l'analyse de Fourier ainsi que c) l'analyse en tiers d'octave du signal B.

TABLEAU 1 Valeur des paramètres des 3 signaux impulsionnels
Parameter values for the 3 impulse signals

Signal	Lp max (à 25 cm) (dB)	contenu spectral (1/3 octave) fréquence inf. (kHz)	sup. (kHz)	temps de montée (msec)	temps de décroissance (msec)	cadence (/sec)
A	140	0,3	1	0,34	0,34	1
B	135	0,3	3	0,15	0,15	1
C	135	0,3	4	0,12	0,12	1

Mise au point de la procédure expérimentale
Optimisation of the experimental procedure

Rappelons que le but de l'étude était d'évaluer l'iso-nocivité de signaux impulsionnels de contenus fréquentiels différents. La détermination des niveaux de pression de crête engendrant un même effet a nécessité plusieurs essais. La figure 4 résume les étapes franchies pour atteindre, par un minimum d'essais, un DTS de 8 à 12 dB après 24 minutes d'exposition pour chacun des signaux et chacun des sujets.

Il s'agissait, en premier lieu, d'exposer le sujet à un signal (A, B ou C) à un niveau de pression de crête ($L\hat{p}$) présumé inoffensif pour l'audition (environ 120 dB crête) pendant 4 minutes. Deux minutes après la fin de l'exposition, le DTS (DTS2) était mesuré. Selon la quantité de

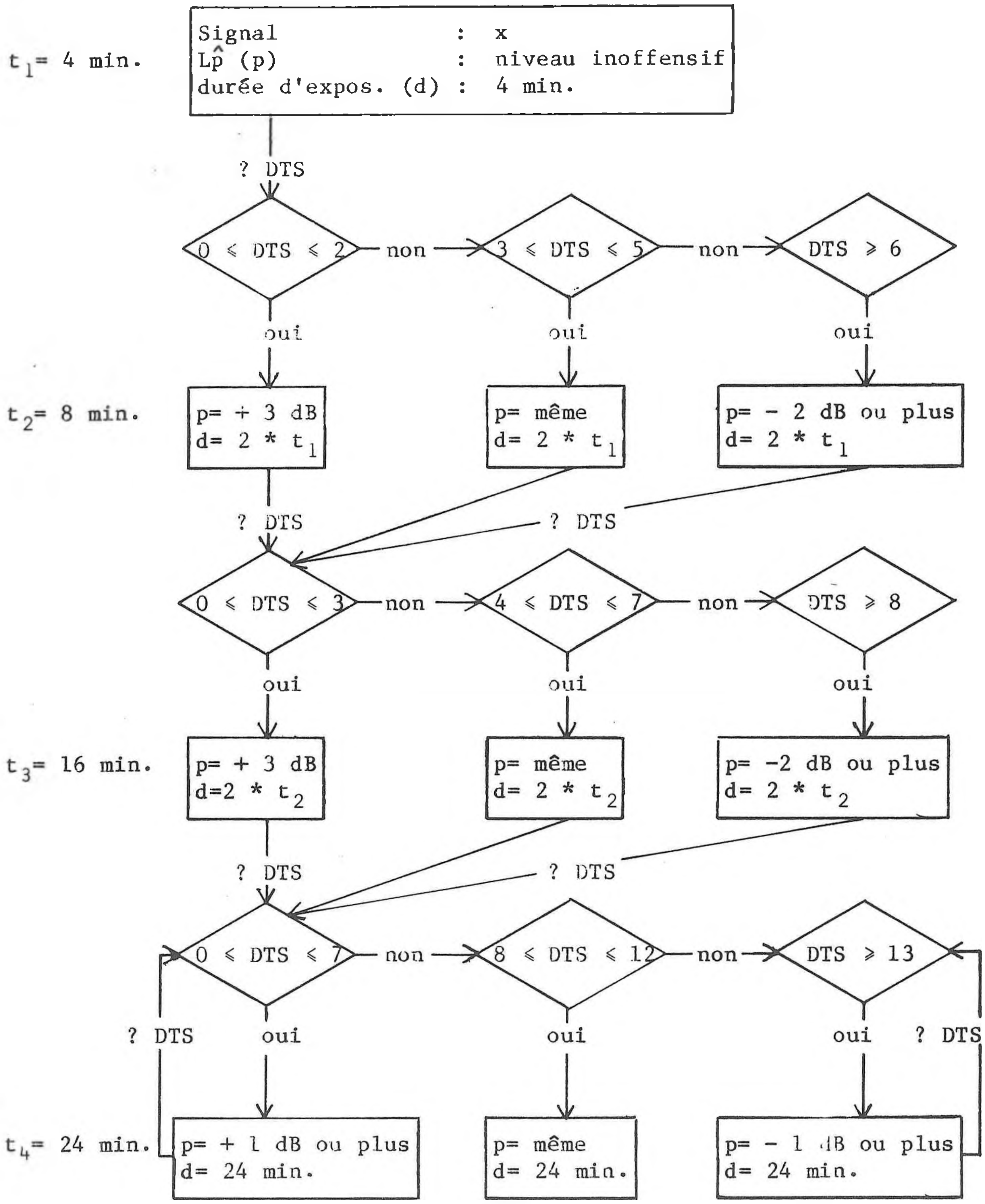


Figure 4 Détermination de la pression de crête d'un signal engendrant un 8 ⩽ DTS ⩽ 12 après 24 minutes d'exposition à l'oreille et à la fréquence la plus sensible.
Flow chart for determining the peak pressure of a signal causing 8 ⩽ TTS ⩽ 12 after a 24 minute exposure to the most sensitive ear and frequency.

DTS, diverses décisions pouvaient ête prises; si le DTS était compris entre 0 et 2 dB, le Lp était augmenté de 3 dB et la durée d'exposition "d" doublée; si le DTS oscillait entre 3 et 5 dB, le Lp était maintenu et la durée était doublée; enfin, si le DTS dépassait 6 dB, le Lp était diminué de 2 dB ou plus tout en doublant la durée. Ce processus était maintenu jusqu'à l'atteinte d'un DTS compris entre 8 et 12 dB après 24 minutes d'exposition.

Conditions d'exposition
Conditions of exposure

Après avoir déterminé les niveaux de pression de crête pour chacun des signaux et chacun des sujets, l'expérimentation comprenait les étapes suivantes:

1- exposition de 24 minutes au premier signal;

2- mesure du DTS2;

3- période de récupération variant de 20 à 24 heures;

4- exposition de 16, 8 et 4 minutes au même signal qu'en 1, avec récupération entre chaque exposition;

5- pour certains sujets et certains signaux, des expositions de 32 et de 48 minutes ont été faites afin de confirmer ou d'infirmer la présence d'une asymptote.

Au total, le nombre d'expositions et d'essais pré-exposition s'élevaient à environ 30 par sujet.

Analyse des données
Data analysis

Pour tracer les courbes d'acquisition des DTS, un modèle mathématique dérivé de la fonction de Gompertz [33] a été utilisé. Ce modèle prend la forme de:

$$DTS(t) = V * g^{t^h} - V * g$$

où DTS(t) = DTS au temps t,
V = paramètre,
g = paramètre,
h = paramètre,
t = durée d'exposition.

L'asymptote a été calculée à partir de la formule suivante: DAS = V * (1 - g). L'asymptote était considérée atteinte au temps t pour lequel le DTS était égal à 95% de la valeur de l'asymptote.

RÉSULTATS
RESULTS

Les figures 5, 6 et 7 présentent les résultats pour chacun des sujets exposés aux signaux A, B et C. Chaque figure sera analysée individuellement.

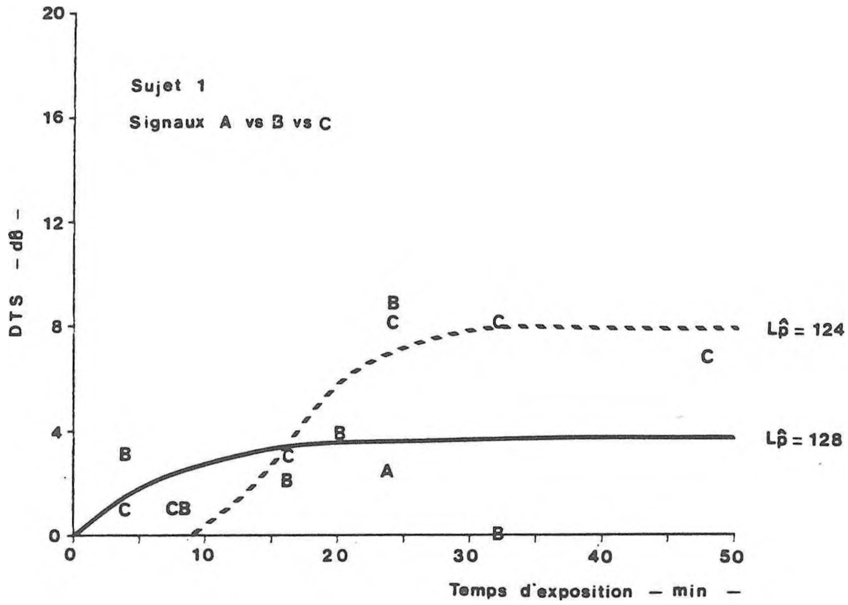


Figure 5 Comparaison des courbes d'acquisition de la fatigue auditive du sujet 1 pour les signaux A ($L\hat{p}$ = 136 dB), B ($L\hat{p}$ = 128 dB, DAS = 3,8 dB) et C ($L\hat{p}$ = 124 dB, DAS = 8 dB).
TTS growth curves of subject 1 for signals A ($L\hat{p}$ = 136 dB), B ($L\hat{p}$ = 128 dB, ATS = 3,8 dB) and C ($L\hat{p}$ = 124 dB, ATS = 8 dB).

A la figure 5, l'exposition au signal C met en évidence l'atteinte d'une stabilisation après environ 30 minutes; ceci confirme la présence d'une asymptote. Dans le cas du signal B, nous avons fait face à une variabilité imprévisible, incontrôlable et inexpliquée (soit 0 et 9 dB de DTS après 32 et 24 minutes d'exposition). niveau de pression de crête du signal A (136 dB) a induit une gêne importante mais n'a engendré que 2 dB de DTS après 24 minutes d'exposition. Pour ce sujet, l'objectif méthodologique de la mesure de l'équinocivité n'a donc pu être atteint avec les signaux étudiés. On doit toutefois noter que le signal C (riche en hautes fréquences) est plus nocif que le signal A (riche en basses fréquences) et ce, à un niveau crête inférieur de 12 dB.

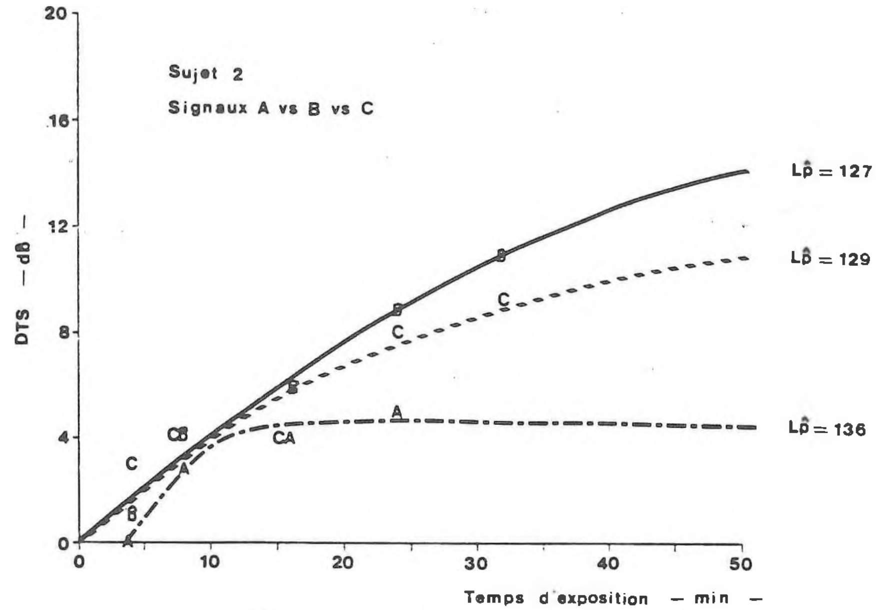
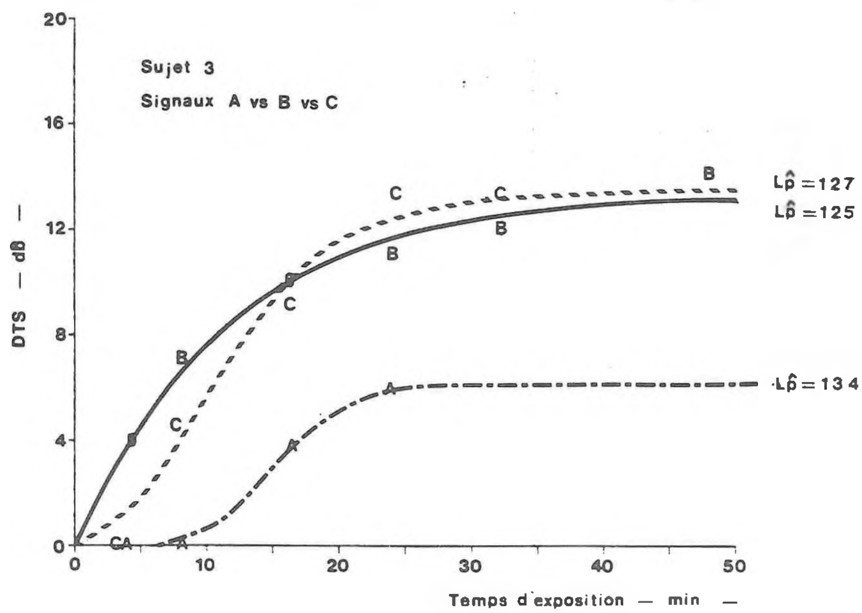


Figure 6 Comparaison des courbes d'acquisition de la fatigue auditive du sujet 2 pour les signaux A (Lp̂ = 136 dB, DAS = 4,5 dB), B (Lp̂ = 127 dB, DAS = 17,6 dB) et C (Lp̂ = 129 dB, DAS = 12,4 dB). TTS growth curves of subject 2 for signals A (Lp̂ = 136 dB, ATS = 4,5 dB), B (Lp̂ = 127 dB, ATS = 17,6 dB) and C (Lp̂ = 129 dB, ATS = 12,4 dB).

A la figure 6, on observe, pour le signal A, une nette stabilisation. Ce ne semble pas le cas des signaux B et C, une inflexion de la courbe n'ayant pas été obtenue. Malgré cela, on note une différence très systématique entre les effets des 3 signaux. le signal A étant considérablement moins nocif que les 2 autres.



Figue 7 Comparaison des courbes d'acquisition de la fatigue auditive du sujet 3 pour les signaux A (Lp̂ = 134 dB, DAS = 6,3 dB), B (Lp̂ = 125 dB, DAS = 13,4 dB) et C (Lp̂ = 127 dB, DAS = 13,5 dB). TTS growth curves of subject 3 for signals A (Lp̂ = 134 dB, ATS = 6,3 dB), B (Lp̂ = 125 dB, ATS = 13,4 dB) and C (Lp̂ = 127 dB, ATS = 13,5 dB).

A la figure 7, pour les trois signaux, on observe, après environ 30 minutes d'exposition, une stabilisation du processus d'acquisition du DTS dans le temps. La présence d'un DAS est très clairement confirmée pour les signaux B et C. Le signal A a engendré un DTS de 6 dB avec un niveau de pression de crête de 134 dB, niveau maximal toléré par le sujet. Le degré de nocivité de ce signal est de beaucoup inférieur à celui des deux autres qui ont engendré un DAS supérieur de 6 dB à des niveaux crêtes inférieurs de 7 à 9 dB (soit un facteur de 5 à 8 en terme d'énergie acoustique). Par ailleurs, on note que la comparaison des effets des signaux B et C représente une excellente illustration de l'équinocivité.

CONCLUSION
CONCLUSION

Les résultats de ce travail exploratoire confirment l'intérêt et l'utilité de l'approche développée pour étudier la nocivité des bruits impulsionnels. En utilisant non pas des valeurs moyennes de DTS mais bien des courbes d'acquisition du DTS, on obtient des comparaisons fiables entre les effets des différents signaux impulsionnels. Au minimum, ces comparaisons sont ordinales. Dans plusieurs cas, elles s'expriment directement en variations des paramètres physiques du bruit pour obtenir un même effet stable.

Pour généraliser l'emploi de cette méthodologie, il reste: a) à préciser les facteurs qui déterminent le temps pour atteindre l'asymptote, b) à déterminer la relation Lp-asymptote pour guider le choix des conditions à étudier et c) à mieux comprendre l'origine de la variabilité imprévisible de certains résultats (sujet 1, signal B).

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Personnels de recherche demandés | Research personnel sought

GROUPE D'ACOUSTIQUE DE L'UNIVERSITE DE SHERBROOKE

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GAUS - un groupe dynamique d'acoustique, comprenant environ 18 professionnels, techniciens et étudiants oeuvrant dans la recherche appliquée au niveau théorique et expérimental.

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RECHERCHES COURANTES

- Champs sonores en locaux - prévision, mesures et aspects subjectifs
- Intensimétrie - mesure 3D, identification des sources, représentations vectorielles
- Propagation du son à l'extérieur - mesure et prévision; effets d'écrans
- Matériaux acoustiques - l'impédance des absorbants, du sol, des toitures
- Réduction du bruit dans les domaines textiles, pâtes et papiers, embouteillage

Nous recherchons des chercheurs, des étudiants au 2è ou 3è cycle ou des stagiaires, pour effectuer des travaux de recherche sur les sujets ci-haut mentionnés. Les candidats intéressés devraient écrire à Monsieur Jean Nicolas, et joindre leur curriculum vitae.

GAUS - a dynamic acoustics group, consisting of about 18 professionnels, technicians and students working on theoretical and experimental, state-of-the-art, applied research.

EQUIPMENT held includes the B&K 3360 sound intensity analyser, B&K 2032 two-channel FFT analyser, PDP-1173, HP9816 and HP9826 computers and a semi-anechoic chamber.

CURRENT RESEARCH INTERESTS

- Enclosure sound fields - prediction, measurement and subjective aspects
- Sound intensity - 3D measurement, noise-source identification, vector representation
- Outdoor sound propagation - prediction and measurement; barrier insertion loss
- Acoustic materials - impedance of absorbent materials, ground, factory roofs
- Industrial noise control - textile, pulp and paper and bottling industries

Researchers, Masters or Ph.D students or summer students, are sought to work on any of the above topics. Interested candidates should write to Professor Jean Nicolas, sending a curriculum vitae. Non-francophone applicants are welcomed - supervision may be in English though courses are in French. Applicants should have some knowledge of French and be willing to integrate into this mainly Francophone group and milieu.

SURVEY OF CANADIAN ACOUSTICAL CONSULTANTS

J.S. Bradley

CANADIAN ACOUSTICS has carried out its first ever survey of Canadian acoustical consultants. The information in this survey was obtained from consultants responses to a questionnaire printed in our January issue. Thus the information is based only on questionnaire responses and CANADIAN ACOUSTICS has not made any attempt to verify its accuracy. The survey was carried out as a service to the Canadian acoustical community, and to provide at least a rough indication of Canadian acoustical consultants and their areas of specialization. It is not intended that CANADIAN ACOUSTICS or the Canadian Acoustical Association endorses any of these consultants as we have no way of judging the accuracy of the information or the abilities, skills, or training of the companies and individuals listed below. We hope that the survey results will at least help people to realize that there are a large number of acoustical consulting companies with quite varied experience here in Canada.

A total of 35 different companies are included in the results. A few responses were not included because they did not represent companies or sections of companies that were primarily involved in consulting in the areas of sound and vibration. That is, they were not judged to be Canadian acoustical consultants.

The companies and their responses are listed alphabetically by region of the of the country. Five regional groupings were created: Atlantic, Quebec, Ontario, Western, and Pacific to provide a convenient break down of the companies. There are two tables of information. The first lists the company name address and telephone number along with a short 3 line description of specialized expertise. This three line description was condensed from usually longer texts provided by the respondents. We have tried our best to include the major points from the original texts.

The second table includes the detailed survey response information again listing the companies alphabetically within each region of the country. The first two columns include (1) the equivalent number of full-time employees working in acoustical activities, and (2) the age of the company. It is not clear that the number of employees was always given as equivalent full time employess, and in some cases fractional responses were rounded up to the next whole number. The age of the company can also be misleading, and does not usually represent the number of years of experience of the principals. The next 14 columns of the table indicate the areas of specialization of each company. The 14 areas are as follows:

(1) Industrial noise control

(2) Hearing conservation

(3) Machinery noise control

(4) Noise Control in buildings

(5) Environmental noise

(6) General acoustical design of interior spaces

(6) Specialized acoustical design of theatres, studios, etc.

(7) Electroacoustics and sound system design

(9) Mechanical vibrations of machinery

(10) Structural vibrations of buildings

(11) Underwater and marine acoustics

(12) Ultrasonics

(13) Development of instrumentation

(14) Other

The "other" responses are further explained at the bottom of the main table. It is seen from the table that most expertise is concentrated in the areas of columns 1. 3. 4. 5. 6, and 7 which can be summarized as noise control and acoustical problems related to buildings and the environment. At the other extreme, only one company reported expertise in ultrasonics.

The last 4 columns of the table indicate special facilities that the companies may have. The four columns represent responses to the following four questions concerning special facilities:

(1) None

(2) Instrumentation for conventional measurements

(3) More advanced instrumentation and computer-based analysis systems

(4) Special measurement chambers

Although two companies reported having no instrumentation or special facilities, most companies indicated having instrumentation for conventional measurements. The details of special measurement facilities are given at the bottom of the table. It is not always clear that the facilities belong to the consultant or whether he can only obtain access to these facilities.

The information in this survey should be regarded only as a rough guide to a companies capabilities. One should, of course, verify particular details that may be of concern to you by contacting companies directly. We hope at least you will now find it much easier to know where to go to get further information. The survey is a new idea that required some effort to produce. Any comments or criticisms would be most welcome and would be helpful in deciding whether to repeat the survey next year.

Table I. Canadian Acoustical Consulting Company Addresses by Region

ATLANTIC REGION

(1) Atlantic Acoustical Associates P.O. Box 2520 DEPS Dartmouth, N.S. (902) 425-0044	Over 25 years experience in architectural and industrial noise and vibration control and sound system design on major projects across Canada and United States.
(2) H.W. Jones & Associates Ltd. 374 Viewmont Dr., Allen Heights Tantallon, N S., B0J 3J0 (902) 435-4486	Over 44 years experience in design and development of ultrasonic apparatus, image processing techniques, non-destructive evaluation, and medical diagonosis.

QUEBEC REGION

(3) Acouscience Inc. 83 Trenton Mt. Royal, Quebec, H3P 1Z1 (514) 733-2088	Specializes in architectural acoustics for concert halls, theatres, cinemas, recording studios, film studios, radio and television studios, video studios, etc.
(4) W. Bradley Engineering Suite 502, 3600 Ridgewood Ave. Montreal, Quebec, H3V 1C2 (514) 735-3846	Over 23 years experience in architectural acoustics, noise control, acoustical research and teaching. Consulting services in all aspects of acoustics.
(5) Groupe-Conseil Roche Ltée 2535 Boul. Laurier Ste. Foy, Québec, G1V 4M3 (418) 871-9600	
(6) Groupe JMLA Inc. 2900 Quatre-Bourgeois Ste. Foy, Québec, G1V 1Y4 (418) 653-5201	As well as acoustical/vibration engineering dept. company has total of 64 employees in areas including mechanical, electrical, structural, energy engineering.

(7) Ghislain L'Hereux
911 Rang St. Antoine
Ste. Feréol-les-Neiges. G0A 3R0
(418) 826-2589

(8) MJM Conseillers en Acoustique
MJM Acoustical Consultants
6555 Cote des Neiges. Suite 440
Montreal, Québec. H3S 1A6
(514) 737-9811

The firm operates in both official languages, and specializes in architectural acoustics and noise control in buildings, particularly multiple residences.

(9) Silentec Ltd.
785 Plymouth, Suite 304
Montreal, Quebec, H4P 1B2
(514) 731-3397

Comprehensive testing and design services, $200K instrumentation for surveys, intensity, coherence, correlation, modal analysis, active noise control.

(10) SNC Inc.
1 Complexe Desjardins
Desjardins Postal Station
Montreal, Quebec, H5B 1C8
(514) 282-9551

Engineering and analysis services to resolve potential or existing acoustical/vibration problems in industrial noise control, environmental noise, building acoustics.

ONTARIO REGION

(11) APREL Inc.
38 Antares Dr.
Nepean, Ont., K2E 7V2
(613) 727-0334

Testing to Canadian, U.S., and international standards. Research in telecommunications electroacoustics and electromagnetics.

(12) Barman Coulter Swallow Assoc.
1 Greensboro Dr., Suite 401
Rexdale, Ont., M9W 1C8
(416) 245-7501

Broad engineering experience in instrumentation, engineering analysis, structural and mechanical design. Challenges lead to cost effective designs.

(13) S.A. Boruschak
P.O. Box 382
Oakville, Ont., L6J 1P4
(416) 842-2451/ 845-5049

Architectural designs for residences in noisy areas. The firm serves clients primarily but not exclusively in the Golden Horseshoe area of Ontario.

(14) Canadian Astronautics Ltd.
1050 Morrison Dr.
Ottawa, Ont., K2H 8K7
(613) 820-8280

Successful projects in ocean science, arctic acoustics, military systems, signal processing and equipment development. Modern labs and equipment.

(15) Enviro-Acoustics
2900 Bathurst St., #1101
Toronto, Ont. M6B 3A9
(416) 789-5828

Involved in impact of road and rail noise on land development. Environmental noise and vibration monitoring and consulting in general acoustics.

(16) General Acoustics of Sudbury Ltd.
405-65 Larch St.
Sudbury, Ont., P3E 1B5
(705) 675-7901

(17) Group One Acoustics Inc.
4 Budgell Terrace
Toronto, Ont., M6S 1B4
(416) 762-5452

Specializes in acoustic design of recording studios, film, video, and entertainment facilities. Sound system and acoustic design churches, theatres, etc.

(18) Hatch Assoc. Ltd.
21 St. Clair Ave. East
Toronto, Ont., M4T 1L9
(416) 962-6350

Acoustical staff backed up by full service engineering consulting company serving wide range of clients. Industrial backup leads to cost effective solutions.

(19) Hooker Noise Control Inc.
270 Enford Rd.
Richmond Hill, Ont., L4C 3E8
(416) 884-6070

Consulting, designing, and manufacturing facility

(20) Industrial Audiometry Services Ltd.
92 Rutherford Rd. North
Brampton, Ont., L6V 2J2
(416) 453-0097
1 Alayne Cresc.
London, Ont., N6E 2A2
(519) 681-3830

Three mobile facilities serving Ontario clients featuring manual audiometry. Dosimeters and related instrummentation for noise surveys.

(21) Northern Acoustics Ltd.
32 Windsor Cresc.
Sudbury, Ont., P3E 1Z5
(705) 675-7901

(22) Spaarg Engineering Ltd.
2173 Vercheres Ave.
Windsor, Ont., N9B 1N9
(519) 254-8527

On site measurements, predictions, analysis, and recommendations for residential and commercial development, industrial noise control, research.

(23) T.U.V. Rheinland
480 University Ave., Suite 1012
Toronto, Ont., M5G 1V2
(416) 596-7607

Canadian office of German consulting and testing organization. Advanced prediction of industrial and traffic noise, groundborne vibration.

(24) S.S. Wilson and Assoc.
(Division of MHG Eng. Inc.)
1179 Finch Ave. West
Downsview, Ont.
(416) 665-8427

(25) Valcoustics Canada Ltd.
30 Drewry Ave., Suite 502
North York, Ont. M2M 4C4
(416) 223-8191

WESTERN REGION

(26) Arcos Acoustical Consulting Ltd.
2540 Toronto Cresc.
Calgary, Alberta
(403) 284-9590

Expertise in noise and vibration control for a wide range of architectural and environmental projects. Background in building technology.

(27) Bolstad Engineering Assoc. Ltd.
9249 - 48 Street
Edmonton, Alberta, T6B 2R9
(403) 465-5317

20 years experience in HVAC design, building acoustics and noise control. Wide experience including testing facility development.

(28) Comtec Associates Ltd.
75 Woodbine Rd.
Sherwood Park, Alberta, T8A 4A5
(403) 464-3676

Design, specification,and management of electronic communications and sound systems for broadcast, theatre, and recording industry.

(29) D. Olynyk, Acoustical Engineer
8403 - 87 Street, #201
Edmonton, Alberta, T6C 3G8
(403) 465-4125

Experienced consultant in architectural acoustics, noise control, research studies, and product development.

(30) Paige Engineering Co.
19 Trafford Park
Winnipeg, Manitoba, R2M 4Z7
(204) 257-6485

The company functions in a businesss network, where some tasks are subcontracted to other Canadian acoustical consultants.

(31) Western Research
1313 - 44 Avenue, NE
Calgary, Alberta, T2E 6L5
(403) 291-1313

Major environmental impact studies for petro- chemical industry, transportaiton noise and vibration studies, building acoustics.

PACIFIC REGION

(32) Barron and Associates
3284 Heather St.
Vancouver, B.C., V7K 1Z8
(604) 872-2508

Established in 1966, specializing in architectural acoustics, theatre consulting, audio/video systems, industrial/community noise control, mechanical vibration.

(33) Brown Strachan Associates
002 - 1290 Homer St.
Vancouver, B.C., V6B 2Y5
(604) 689-0514

Professional engineers using specialized software to solve acoustical problems in auditoria, offices, mechanical systems, and environmental noise.

(34) Harford Kennedy Lyzun Ltd.
#103 - 3680 East Hastings St.
Vancouver, B.C., V5K 2A9
(604) 291-9991

Active in practically all aspects of acoustical consulting Specialized projects such as marine noise control are carried out throughout Canada.

(35) Whicker Associates
1102 Heyward Ave.
North Vancouver, B.C., V7L 1H4
(604) 987-2655

Consulting in all aspects of noise and vibration control. Professional firm specializing in architectural, building, and community acoustics noise and vibration control.

Table II. Survey Response Summary

Company Name (by region)	Number of Employees	Age of Co.	Areas of Specialization 1	2	3	4	5	6	7	8	9	10	11	12	13	14	Special Facilities 1	2	3	4
ATLANTIC																				
Atlantic Acoustical Associates	3	1	*	*	*	*	*	*	*	*	*	*						*		
H. W. Jones & Assoc. Ltd.	4	1	*		*	*	*						*	*	*			*		
QUEBEC																				
Acouscience Inc.	1	8						*	*									*		
William Bradley Eng.	2	23	*	*	*	*	*	*	*	*	*							*	*	A
Groupe-Conseil Roche Ltée.	3	10	*	*	*	*	*	*	*		*		*					*		
Groupe JMLA Inc.	11	29	*		*	*	*	*	*	*	*	*				a		*	*	
Ghislain L'Hereux	2	8	*		*	*	*	*			*	*						*		
MJM Conseillers en Acoustique	2	2				*	*	*	*								*			
Silentec Inc.	7	8	*		*	*	*	*			*	*			*	b		*	*	B
SNC INC.	4	75	*		*	*	*	*			*	*						*	*	
ONTARIO																				
APREL Inc.	15	4		*		*	*	*		*						c		*	*	C
Barman Coulter Swallow Assoc.	4	6	*		*	*	*	*	*		*	*			*	d		*	*	
Steven A. Boruschak	1	5				*		*										*		
Canadian Astronautics	3	12											*		*				*	D
Enviro-Acoustics	1	1				*	*										*			
General Acoustics Sudbury Ltd.	2	16														h				
Group One Acoustics Inc.	1	6				*		*	*	*								*		
Hatch Assoc.Ltd.	-	31	*	*	*	*	*	*								e		*		
Hooker Noise Control Inc.	4	12	*		*	*			*							f		*		
Industrial Audiometry Services Ltd.	3	12	*	*														g	*	
Northern Acoustics Ltd.	2	16	*	*														*	*	
Spaarg Eng. Ltd.	2	5	*		*	*	*											*		
T.U.V. Rheinland	1	2+	*		*	*	*	*	*	*	*	*						*	*	
S.S. Wilson & Assoc.	3	11	*	*	*	*	*	*	*		*	*				i		*	*	
Valcoustics Canada Ltd.	10	18#	*			*	*	*	*	*	*	*							*	
WESTERN																				
ARCOS Acoustical Consulting Ltd	1	3				*	*	*	*		*							*		
Bolstad Eng. Assoc. Ltd.	1	24	*		*	*	*	*	*									*	*	
Comtec Assoc. Ltd.	2	17						*	*	*								*		
Donald Olynyk Acoustical Eng.	1	13	*		*	*	*	*	*									*		
Paige Eng. Co.	1	5	*			*		*	*	*						j		*		
Western Research	2	20	*		*	*	*	*	*		*	*						*	*	
PACIFIC																				
Barron & Assoc.	6	20	*		*	*	*	*	*	*	*	*	*			*		*	*	
Brown Strachan Assoc.	2	20	*	*	*	*	*	*	*	*	*	*	*			*		*	*	
Harford Kennedy Lyzun Ltd.	3	15	*		*	*	*	*	*		*		*					*		
Whicker Assoc.	1	2	*		*	*	*	*	*		*							*		

Table II. Survey Response Summary (cont).

(a) soil mechanics
(b) applied research
(c) communications transmission performance
electromagnetic capability
product reliability
(d) finite element structural analysis
seismic qualification, analysis and testing
(e) transit system noise
(f) noise control in offices and data centres
(g) audiometric calibration
(h) diagnostic medical hearing testing
(i) mechanical engineering
(j) audio-visual systems

(A) anechoic, reverberation chambers
(B) acoustic wave guide
(C) 7500 ft^3 anechoic chamber
IEC listening room
shielded rooms
(D) ice covered water

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BRANCHES THROUGHOUT CANADA

BOOK REVIEW
"Concert Hall Acoustics"
by Y. Ando
published by Springer-Verlag

Concert hall acoustics is often thought to be one of the glamour areas of acoustics, and a new book on the subject should attract a wide readership. When the author is well known as one of the key contributors to establishing a modern scientific basis for the subject of concert hall acoustics, a wide readership should be even more certain. Professor Ando's book is certainly a very impressive compilation of recent research results. There are very few authors in any area of specialization who could produce such an account of largely their own research over a period of less than 20 years. In spite of the great appeal of the subject and the author, many readers will be dissapointed by this book. It is certainly not a text book on the subject; it is a compilation of recent research results largely by the author. As such there are many conclusions that have not yet been fully exposed to criticism and the test of time. In addition the book is written in a very heavy mathematical style that many readers will find difficult to follow. For example even in the introduction the author resorts to the mathematical notation of set theory to introduce the general problem of relating the many dimensions of subjective judgements and physical measurements. Thus the book seems to be intended for researchers and not more general readers including many concert hall consultants. It is disappointing that many who could benefit from at least some of the information in this book will probably not try to read it.

The book is composed of seven chapters and appendices that follow an interesting foreword by Professor M.R. Schroeder. The foreword is interesting in its own right because it summarizes the situation that lead up to Ando's work as seen by Schroeder, another very notable expert in the field. This includes yet another description of the acoustical problems of the Lincoln Center in New York. After the Introduction, the chapters are titled: "Sound Transmission Systems", "Simulation of Sound Fields", "Subjective Preference Judgements", "Prediction of Subjective Preference in Concert Halls", "Design Study", and "Acoustical test Techniques for Concert Halls". Some chapters such as chapter 4 on "Subjective Preference Judgements" contain a wealth of information on various aspects of one topic, but others such as the chapter on "Sound Transmission Systems" are more of a grab bag of unrelated topics. For example this chapter includes discussion of: the autocorrelation function to describe source signals, sound reflections from various surfaces, and physical details of the hearing system.

The fifth chapter on the prediction of subjective preference, starts with a section on how the brain may process auditory signals from the two ears. This is followed by more down-to-earth information concerning combining the results of Ando's subjective tests to predict the preference of concert halls. This includes example calculations for a simplified hall shape modelled on the Boston Symphony Hall, and brings together Ando's principal concepts in an interesting and practical way. The sixth chapter, although titled "Design Study", is a combination of quite theoretical discussions of information on three quite separate topics. These are: quadratic residue type diffusers, propagation over audience seating, and comments on the subjective aspects of stage design. It is almost as if Ando was determined to combine the results of his many journal papers by simply appending one to another to produce a book.

The last chapter includes a brief theoretical discussion of how each of the acoustical quantities may be measured in concert halls. It does not consider the more practical problems associated with these measurements. The appendices contain a range of further information including more subjective results, tables of interaural cross correlation functions as a function of angle and music sample, and finally a computer program that apparently calculates impulse responses using the Fast Hadamard Transform method.

My major criticism of the book would be that it presents new and largely untested research results in a light that suggests that the story is now complete. There is little discussion of the relative merits of particular conclusions. An obvious example would be the results of Figure 4.17 that suggests that for a Mozart symphony an optimum reverberation time based on Ando's theory, using the autocorrelation function of the source signal, would be about 1 second. This is, of course, considerably different from other optimum reverberation time values for this type of music and it at least deserves some discussion. This book contains a wealth of interesting information and anyone contemplating reasearch in concert hall acoustics must read it. It would be useful reading for concert hall consultants and other interested readers, but its style is not intended to introduce newer concepts to the general reader.

J.S. Bradley, Institute for Research in Construction
National Research Council, Ottawa

A NEW CANADIAN STANDARD ON MEASUREMENTS OF OCCUPATIONAL NOISE EXPOSURE

The new CSA Standard Z107.56, Procedure for Measurement of Occupational Noise Exposure, is expected to be the first of its kind in the world when it appears in 1986. It was written by Alberta Behar of Ontario Hydro and Tim Kelsall of Hatch Associates Limited for the CSA Industrial Noise Subcommittee. It underwent an extensive review by representatives of major industries.

The standard was prepared at the request of the Working Group on Occupational Noise Exposure and Hearing Conservation of the Federal Provincial Advisory Committee on Occupational and Environmental Health. This working group has prepared a Guideline for Regulatory Control of Occupational Noise Exposure and Hearing Conservation which includes a model occupational noise regulation and associated codes. This model regulation requires that occupational noise exposure be measured using the procedures in the new CSA Standard.

ISO 1999, Section 4, briefly discusses measurement procedures, however, this is done only in a very cursory fashion and does not provide sufficient guidance in actually performing the required measurements.

ANSI is circulating the latest draft of their standard: Measurement of Occupational Noise Exposure, prepared by the S12-19 working group for comments. The standard is not likely to be published in the near future.

Because it was written with extensive consultation with industry, it is expected that any company who has made a serious attempt to quantify their employees' noise exposure should find that their procedures already meet the requirements of the standard.

The standard describes methods for measuring the noise exposure of employees using dosimeters, integrating sound level meters and even ordinary sound level meters if the noise is steady enough. It provides procedures for sampling the noise exposure of individuals. It also provides procedures for measuring the noise exposure of groups of employees working in similar acoustical environments. Thus if sound levels are uniform throughout an operation, the noise exposure of all employees can be determined by sampling only a few.

The sampling time depends on the steadiness of the noise. Where sound levels are steady and continuous a few minutes of measurement may be sufficient. On the other hand, employees exposed to unpredictably varying sound levels will require more attention.

The standard is expected to be published in 1986 and will be available from the Canadian Standards Association for a nominal charge.

Further information is available from:

Mr. Tim Kelsall
Hatch Associates Ltd.
21 St. Clair Avenue,
East Toronto, Ontario M4T 1L9

Mr. Alberto Behar
Ontario Hydro
Safety Services Department
757 McKay Road
Pickering, Ontario
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The Digital Sona-Graph® model 7800 is a DC-32kHz spectrum analyzer designed for the analysis and display of non-stationary signals (such signals include speech, Doppler shifts from Ultrasound and telemetry signals, sonar and radar returns, animal sounds, music, heart sounds or any sound that has frequency characteristics which change over time). The complex nature of these signals requires an analyzer which incorporates the features of a sound spectrograph, a waveform printer, signal splicer/editor and a spectrum analyzer.

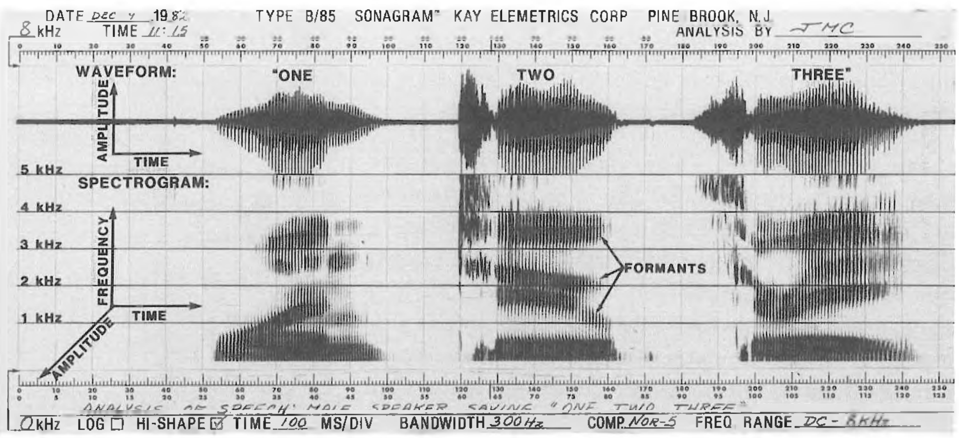
SOUND SPECTROGRAPH

The 7800 captures and stores the input signal to a real time rate of 32kHz in a large 128K word (each word is 11 bits wide) solid state memory (RAMs). The 7800 can accept single or dual channel input. Once stored, the signal(s) can be analyzed (to a 60dB dynamic range), displayed and printed in many ways. The spectrographic display is most revealing for non-stationary signals which are characterized by spectral (frequency) changes over time. This 3-D display (amplitude vs. frequency vs. time) is shown to the right.

- **Print Resolution: 1000 (H) X 400 (V) X 23 Grey Scale Levels**

SPECTRUM ANALYZER

Any two points in the large memory can be analyzed and printed as a standard (frequency vs. amplitude) spectrum analysis display. The 7800 also has an optional FFT module which can analyze any of the stored 512 blocks of data (each block has 256 data points) in 0.005 seconds for a real time bandwidth up to 20kHz. The input signal can also be analyzed in real time for monitoring. The large input buffer memory minimizes triggering problems. An oscilloscope is required for the display of this real time FFT analysis.



SIGNAL SPLICER/EDITOR

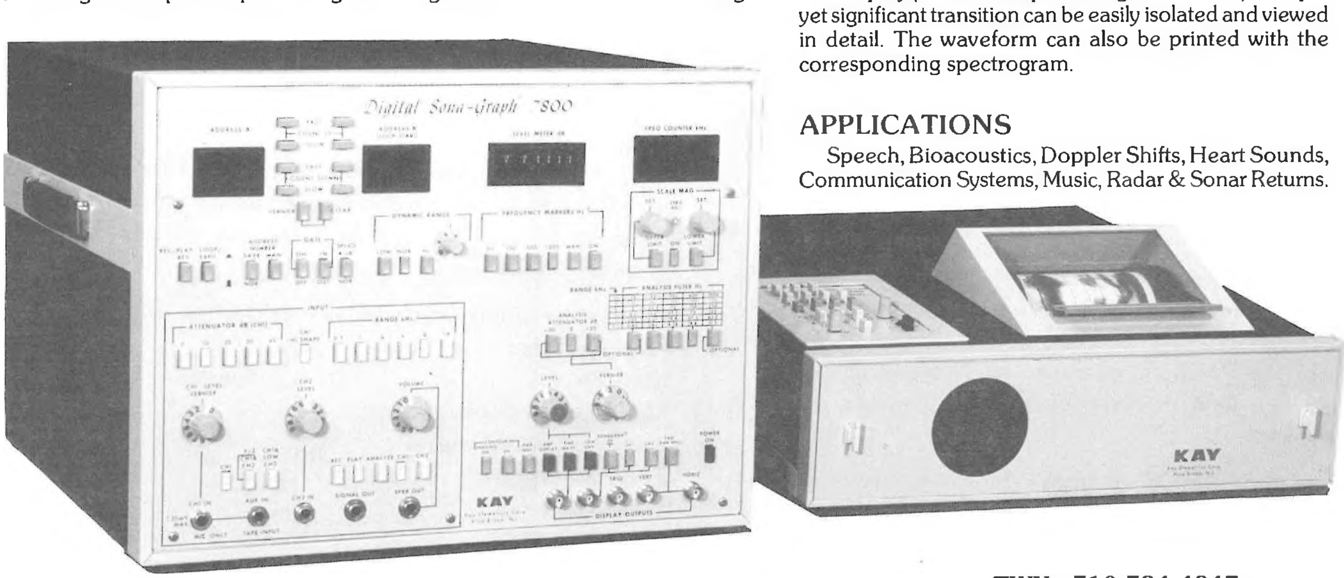
The large 128K word (by 11 bit) memory can record and store 5.12 seconds (in the 8kHz range) of input signal. The splicer/editor feature lets the user listen to or remove, selected portions of the audio signal or splice separate segments together.

AUDIO WAVEFORM PRINTER

Print the entire stored waveform or just selectively expand portions of the stored signal. Unlike expensive high speed oscillographs, the 7800 makes it easy to select only certain segments for display (see the sample Sonagram® above). A rapid yet significant transition can be easily isolated and viewed in detail. The waveform can also be printed with the corresponding spectrogram.

APPLICATIONS

Speech, Bioacoustics, Doppler Shifts, Heart Sounds, Communication Systems, Music, Radar & Sonar Returns.



TWX: 710-734-4347

KAY Kay Elemetrics Corp. 12 Maple Avenue, Pine Brook, NJ 07058 U.S.A. Telephone: (201) 227-2000

NEWS

CAA ANNUAL BUSINESS MEETING

The CAA Annual Business Meeting will be held between 16:00 and 18:00 hours on Tuesday, 29 July 1986 in Room 203 B & D in the Metro Toronto Convention Centre. It had previously been decided to hold the annual meeting during the 12th ICA and to not have a technical meeting this year. The Directors' Award for the best paper in CANADIAN ACOUSTICS by an author under 35 years of age will also be presented at the annual meeting.

NAME CHANGE

The Canadian Association of Speech-Language Pathologists and Audiologists
L'Association Canadienne des orthophonistes et audiologistes
#311-44 Eglinton Avenue West
Toronto, Ontario
M4R 1A1

We have a new name! The Canadian Speech and Hearing Association is now the Canadian Association of Speech-Language Pathologists and Audiologists. CASLPA will continue to ensure the same high quality service to the communicatively handicapped; to help develop and advance services and knowledge in Canada; to provide the communicatively impaired with accurate information regarding the nature and treatment of their disorder; to assist those in the community seeking professional help.

Let's work together in

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FIFTH PAN PACIFIC CONFERENCE ON NON-DESTRUCTIVE TESTING

April 7-10, 1987
Call for Papers

Following the unqualified success of the previous conference in Sydney, Australia (1983), the Canadian Society for Nondestructive Testing, Inc. is pleased to host the Fifth Pan Pacific Conference on Nondestructive Testing to be held in Vancouver, B.C., Canada on April 7-10, 1987.

Papers are invited on recent developments in application, investigation or research of state-of-the-art technologies related to:

Acoustic Emission
Electrical & Magnetic Methods
Infrared
Penetrating Radiation
Sonics
Penetrant & Visual Methods

Authors wishing to submit papers should indicate their intent as soon as possible, providing a title and abstract of at least 300 words by July 1, 1986. Papers (of 3000 to 5000 words) are required by December 1, 1986.

Submissions and inquiries should be addressed to:
Chairman Technical Program
Fifth Pan Pacific Committee on NDT
P.O. Box 6245
Station F
Hamilton, Ontario
Canada, K9C 5S3
Tel.: (416) 387-1666

IHC '86

IHC '86, the International Innovative Housing and Components Exhibition, will be held November 12-16, 1986 at the Metro Toronto Convention Centre, Toronto, Canada.

Designed to promote international development and implementation of leading edge housing technology, the IHC '86 exhibition and conference will provide an educational forum for housing and components manufacturers, builders, contractors and developers, architects and engineers, urban planners, government housing officials, construction materials suppliers, financial institutions and the consuming public.

The exhibition represents a multi-lateral trade opportunity for manufacturers, suppliers and users from North America, the U.K., Scandinavia, Europe and Japan who will display new and innovative housing technology and components designed for every stage of external and internal home construction.

IHC '86 is sponsored by the Canadian Housing Design Council in co-operation with the Canadian Home Builders Association and the Canadian Manufactured Housing Institute.

For further information on the exhibition and conference, contact:
IHC '86
Manumod Exhibitions Inc.
209-77 Mowat Avenue
Toronto, Ontario
M6K 3E3
(416) 533-4888

ASTM NEWS

The Task Group on Practices and Criteria for Audiometric Booths of American Society for Testing and Materials (ASTM) Committee E-33 on Environmental Acoustics seeks people interested in developing guidelines for specifying and installing audiometric booths. It was announced at the Committee E-33 meetings in Charleston, SC, on April 14-16 that the Task Group will be discharged if there is no further interest in this activity.

At the request of the California Association of Window Manufacturers (CAWM) Committee E-33 will revise Method E 90 for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions to include specific requirements for testing windows. At a planning Committee Meeting for "Control of Exterior Noises Through Fenestration Products" CAWM representatives asked for revisions to E 90, the development of a single- number rating suitable for common exterior noises, and a standard describing practices for installing windows in a way that will provide maximum possible sound isolation.

The Task Group on Sound Insulation Ratings will consider the CAWM request for a single-number rating. This Task Group is already considering possible rating schemes to supplement the Sound Transmission Class (STC), which is intended to predict sound insulation only for a limited class of interior noises.

The Task Group on Ceiling Insertion Loss Measurements is experimenting with a method to measure how noise from air-conditioning units directly above ceilings is attenuated. The Task Group has found that standard sound transmission loss measurements overestimate the attenuation provided in this situation.

A specification for a standard reference specimen for sound transmission loss tests will be prepared by another E-33 Task Group. Specimens made according to the specification can be used during repeatability and reproducibility testing.

PUBLISHED PROCEEDINGS AVAILABLE

The Second International Congress on Acoustic Intensity was held at the French Centre Technique des Industries Mécaniques (CETIM) in Senlis, France on 1985 September 23-26. The technical information presented at this conference was much more extensive than that presented at the first conference which was also held in Senlis in 1981. The uses of acoustic intensity as a measurement tool in noise control engineering have increased greatly since 1981, and this growth was reflected in the technical information presented at the conference. Among the subjects covered were instrumentation, vector acoustics, sound radiation, intensity in the presence of flow, intensity flow in structures, techniques for determination of sound power, noise source localization, impedance measurements, absorption measurements and sound transmission measurements.

The technical papers presented at this conference have been collected and published in a bound proceedings volume. The volume contains 570 pages of technical papers; 58 are in English and 20 are in French with English abstracts and figure captions. Copies are available for $80.00 (US) plus shipping costs.

INTER-NOISE 85, the 1985 International Conference on Noise Control Engineering was held in Munich, Federal Republic of Germany on September 18-20, 1985. The conference was organized by the German Member of the International Institute of Noise Control Engineering (I/INCE), the VDI-Kommission Lärmminderung. INTER-NOISE 85 was sponsored by I/INCE and the Federal Institute of Occupational Safety in Dortmund, Federal Republic of Germany.

There were 351 technical papers presented at the meeting covering all areas of noise control engineering, including aircraft noise, road traffic noise, machinery noise reduction, sound intensity measurement techniques, modern instrumentation for noise control and noise regulations.

The Proceedings of INTER-NOISE are now available as a two-volume set. A total of 1500 pages of technical information has been published in the Proceedings, and the charge per copy is $80.00 (US).

For copies of either proceedings contact:
NOISE CONTROL FOUNDATION
P.O. Box 3469 Arlington Branch
Poughkeepsie, NY 12603 U.S.A.

NONLINEAR ACOUSTICS

The XI International Symposium on Nonlinear Acoustics will be held in Novosibirsk, USSR, August 24-28, 1987. The Symposium is organized by the Siberian Division of the USSR Academy of Sciences, Lavrentyev Institute of Hydrodynamics, Institute of Thermophysics and Institute of Theoretical and Applied Mechanics. The Section of General Physics and Astronomy of the USSR Academy of Sciences, the Joint Scientific Council "Physical and Engineering Acoustics" of the USSR Academy of Sciences, Andreyev Institute of Acoustics, Institute of Applied Physics of the USSR Academy of Sciences, and Institute of General Physics of the USSR Academy of Sciences will take a great part in its organization.

Contact:
Dr. S. Kinelovsky
Lavrentyev Institute of Hydrodynamics
Siberian Division of the USSR Academy of Sciences
Novosibirsk 630090 USSR

NEW BOOKS

The Physics of the Violin by Lothar Cremer, translated by John S. Allen, M.I.T. Press, Cambridge, MA, USA. 1984.

Musical Structure and Cognition Peter Howell, Ian Cross, and Robert West, Eds. Academic, London, 1985.

Quantifying Music – The Science of Music at the First Stage of the Scientific Revolution, 1580-1650, Volume 23 of the University of Western Ontario Series in Philosophy of Science M.H. Cohen Reidel, Dordrecht, Holland, 1984.

Sundberg (Editor), Studies of Music Performance. Publications issued by the Royal Swedish Academy of Music No. 39, Stockholm 1983.

The Noise Handbook, W. Tempest, Ed. Academic, Orlando, 1985.

A. Kalnins and C.L. Dym (editors), Vibration: Beams, Plates, and Shells., Benchmark Papers in Acoustics, Vol. 8. Dowden, Hutchinson & Ross, Inc., Stroudsburg, PA, 1976.

U. Nigul and J. Engelbrecht (Eds.), Nonlinear Deformation Waves., Springer-Verlag, Berlin-Heidelberg-New York 1983.

Successful Sound System Operation by F. Alton Everest, Tab Books Inc., Blue Ridge Summit, PA 17214, USA.

Damage to Hearing Arising from Leisure Noise, MRC, Institute of Hearing Research, HMSO, United Kingdom, 1985.

Vibration Damping by A.D. Nashif, D.I.G. Jones and J.P. Henderson, Wiley Interscience, 1985.

CALENDAR 1986/87

14–18 July
ICA Satellite, Acoustical Imaging and Underwater Acoustics
Halifax, Nova Scotia

21–22 July
ICA Satellite, Speech Recognition
Montreal, Canada

21–23 July
International Symposium on Nondestructive Characterization of Materials
Montreal, Canada

21–23 July
INTER-NOISE 86
Boston, MA, U.S.A.

21–25 July
Acoustic Emission From Reinforced Plastics
Montreal, Canada

24–31 July
12th International Congress on Acoustics
Toronto, Canada

2–4 August
ICA Satellite, Acoustics and Theatre Planning
Vancouver, Canada

6–8 August
IMACS Symposium on Computational Acoustics
Yale University, New Haven, CT, U.S.A.

24–28 August
International Congress of Audiology
Prague, Czechoslovakia

2–6 September
FASE, European Acoustics Symposium
Sopron, Hungary

21–26 September
10th Congress on Building Research
Washington, DC, U.S.A.

30 September – 3 October
6th International Congress on Nondestructive Testing

7–9 October
International Symposium on Shipboard Acoustics
The Hague, The Netherlands

21–24 October
8th International Acoustic Emission Symposium
Tokyo, Japan

3 – 6 November
Ultrasound '86
Bratislava

12 – 16 November
81st Audio Engineering Convetion
Los Angeles, CA, U.S.A.

8–12 December
Acoustical Society of America
Anaheim, CA, U.S.A.

8 – 12 December
1st Asian Pacific Region Conference on Deafness
Hong Kong

11 – 12 December
International Symposium on Acoustics of Ducts and Muflers (ASME)
Anaheim, CA, U.S.A.

24 – 26 March
DAGA '87 (German Acoustical Association Meeting)
Aachen, Federal Republic of Germany

13 – 16 April
IEEE International Conference on Acoustics, Speech and Signal Processing
Dallas, TX, USA

11 – 15 May
Acoustical Society of America
Indianapolis, IN, USA

1 – 5 June
AIHA Annual Meeting
Montreal

8–10 June
Noise Con'87
State College, PA, USA

15 – 17 September
Inter-Noise '87
Beijing, China

15–19 November
ASME
New York, NY, USA

16 – 20 November
Acoustical Society of America
Miami, FL, USA

INFORMATION FOR AUTHORS		INFORMATION AUX AUTEURS	
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Title	All caps, centred, large type if available.	Titre	Entièrement en majuscule. Centrer.
Author	Name and full mailing address, centred.	Auteur	Nom et adresse postale. Centrer.
Abstract	Short summary, indent left and right margins.	Sommaire	Elargir la marge de chaque côtè.
Sommaire	French translation of Abstract.	Abstract	Traduction anglaise du sommaire.
Text	Single spaced, leave one blank line between paragraphs.	Texte	Simple interligne. Séparer chaque paragraph.
Page Size	8 1/2" x 11"	Pages	8 1/2" x 11".
Margins	Fill the page! Leave only small margins, typically 3/4".	Marge	Réduire à 3/4".
References	Any consistent format, list at end of article.	Références	A la fin de l'article dans un format uniforme.
Figures and Tables	Not too large, insert in text. Include title for each figure and table.	Figures et Tables	Petites tailles. Insérer dans le texte et titrer.
Page Numbers	In light pencil at bottom of each page.	Pagination	En crayon, en bas de chaque page.
Equations	Minimize. Number them.	Equations	Minimiser. Numéroter.
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