

**ACOUSTICS AND MECHANICAL STANDARDS
AT THE NATIONAL RESEARCH COUNCIL**

by

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ABSTRACT

This article reviews current work in the Acoustics and Mechanical Standards Section of the Division of Physics at the National Research Council. The review of each project is placed in the perspective of the overall philosophy governing research decisions in the section, of the evolution of new projects and of administrative changes in recent years.

SOMMAIRE

Cet article passe en revue le travail présentement en cours dans la section d'acoustique et des étalons de mécanique de la division de physique au Conseil national de recherches. Le compte rendu de chaque projet est placé dans la perspective de la philosophie globale gouvernant les décisions de recherche de la section, de l'évolution de nouveaux projets, et des changements administratifs dans ces dernières années.

OVERVIEW

Editor Murray Hodgson has asked me to write an article on the work of the Acoustics Section in the Division of Physics at the National Research Council. A similar article on Auditory Physiology Research in Toronto appeared recently in Canadian Acoustics, Vol. 16, May 1988. The Acoustics Section was profiled once before, in Acoustics and Noise Control in Canada by Edgar Shaw in 1981. In that article Edgar Shaw traced the growth of the Acoustics Section back to its origins in 1929, and I refer the interested reader to his article for the first 52 years of our history. Reading that 1981 article I am struck by numerous impressions; at the one extreme is the continuity of some "generic" projects during the past seven years, and at the other extreme are the significant changes that have occurred with the termination of some projects, the beginning of others, and in the evolution of the ways in which we conduct our business.

Since at least the 1950's, the philosophy governing the Section's work has been to select major areas of acoustical research where there are significant benefits to be derived either from new scientific knowledge or from economic or social improvements. A strong ingredient in our choice of projects is to do the things where we believe we have some special

skills, knowledge or bright idea. The style of research in this laboratory is strongly rooted in physics, attacks both the theoretical and experimental aspects of any problem (so that each substantiates the other), searches for the underlying mechanisms, and attempts to maximize useful output with the minimum expenditure of resources.

It was already apparent in 1981 that the National Research Council was redefining its role so as to provide greater service to the industrial sector of the economy, having spent much of the previous quarter-century helping to build Canadian academia. This caused no great disturbance in the Acoustics Section because working with industry had always been one of our several goals that had been exploited on numerous occasions as opportunity allowed -- quietening of suction rolls for the pulp and paper industry, of nail-making machines for the steel industry, of rock drills for the mining industry, liquid-filled-cushions for ear defenders, and instrument development were just some of our developments that went into commercial production. Administrative changes in 1986 caused the Physics Division of NRC to be combined with the Division of Microstructural Sciences, and the new entity to be subdivided into three Laboratories. One of these three is the Laboratory for Basic Standards, within which the Acoustics Section acquired responsibility for the primary national standard of mass and the derived standards of pressure and density, also the five staff members involved, and was renamed the Acoustics and Mechanical Standards Section.

ACOUSTICAL RESEARCH AND DEVELOPMENT

Our work on sound reproduction and the psychoacoustics of music listening has assisted the Canadian loudspeaker industry in growing from virtually nothing 15 years ago to the point where today it grosses at least \$100 million per year, accounts for more than half the domestic market and is building a significant export market. This success arises from the careful blending of physical tests in anechoic and conventional rooms, controlled listening tests in specially designed rooms, knowledgeable interpretive methods and the skills needed to exploit the results. Our listening room, with its careful control over the frequency, distribution and damping of the room modes was the prototype for the International Electrotechnical Commission standard listening room. Hi-fi loudspeakers today are close to the perfection that is possible at any given price range -- this is a bold statement but indicates that any further improvements in listening will come from new approaches to the complete electroacoustic, room acoustic and listener system. For this reason the laboratory is embarking on a \$2 million, three-year research and development project, in conjunction with a consortium of companies from the Canadian loudspeaker and electronic industries, to develop a "smart" loudspeaker system that will adjust to the listening environment and correct for imperfections in the reproduced signal. The Section's acoustical facilities were used last year for loudspeaker design and evaluation by 33 clients for a total of 94 days.

Another research and development project of long standing aims to understand the mechanisms of noise and vibration generation in small internal combustion engines, such as those in chain saws, and then to reduce this noise by better mufflers, engine design, vibration-isolating handles or other means as appropriate. Design constraints such as size

and weight limitations make it essential to know the relative intensities of the several dominant noise sources (exhaust and intake noise, mechanical noise, surface radiation from the block). The relative magnitudes of the two known forcing functions, the combustion process and piston-cylinder wall impacts, have been investigated and some studies have also been made of the mechanisms responsible for the performance of some significantly improved muffler systems. A balanced design for a quieter device involves treating each of the sound sources by the necessary amount and with the minimum penalty to output power or performance. The design of vibration-isolating mounts, or handles, must allow for associated factors such as the need for stability or precise control.

A closely related project that grew from the work on chain saws involves the study of the epidemiology and cardiovascular mechanisms of damage to the hand and arm caused by exposure to vibration. Our recent work, both in laboratory and field studies, has revealed three patterns of sensorineural response to exposure of the hands to vibration. These patterns were detected by measuring mechanoreceptor-specific vibration perception thresholds using a technique developed here. These studies are conducted under contracts, or as shared cost projects, with the Forest Products Accident Prevention Association, INCO, and individuals at both Laval and McMaster Universities. The process of commercializing the NRC technique for measuring vibrotactile perception thresholds and of working towards the international standardization of the procedure is continuing.

An important goal of the Acoustics Section for many years has been to develop a detailed understanding of the human external and middle ear so that reliable, quantitative predictions of acoustical performance can be made. This will be of use in evaluating audiometric techniques above 8 kHz, for the development of hearing aids, and for the interpretation of various physiological and psychological acoustical effects. The project is proceeding through development of rigorous theory to describe sound propagation along the ear canal and coupling to the middle ear, and experimentally through measurements of real canal geometry and reflection properties of the middle ear. Fifteen ear canals have been measured, 1000 coordinate points each, and previous theories of sound propagation in rigid-walled tubes have been extended to allow for a non-straight tube of variable cross-section terminating in a distributed mechanical load, i.e. the eardrum. Measurement techniques based on phase, rather than the more conventional pressure measurements, have been found very useful in real ears, and experiments on mechanical models have been performed to verify the theory. The improved theory can be applied, making use of the measured data, to calculate the effect of intersubject variations on current audiometric procedures, to evaluate alternative procedures, and to explore the effect of ear canal geometry on hearing aid development.

Over a period of some 15 years our work on sound propagation outdoors has covered all the major interactions of sound waves with ground shape and its surface impedance, and with micrometeorological conditions such as wind and temperature gradients and turbulence.

Application of this new and more precise approach to the basis of prediction schemes has allowed an explanation of the sideline noise up a sloping hillside at Vancouver Airport, the improvement of airport and community noise prediction schemes by several authorities, and more accurate source location by arrays of receivers. We have recently completed theoretical and experimental studies of diffraction over curved surfaces, e.g. berms, of both moderate and very large impedance, and also the coupling of creeping waves across an impedance discontinuity. We are starting the investigation of near-surface seismic waves as we "pursue" airborne sound waves into the ground in order to understand better the surface behaviour of real grounds.

About two years ago we embarked on a project of active, adaptive control of sound fields with the intention of exploring new algorithms for signal processing, the use of multiple sensors for sensing and modifying the acoustic field, and the limitations of such systems. An experimental system allows cancellation of broadband noise in one dimension below about 500 Hz, and will be used to evaluate various control algorithms and derive hardware for more ambitious systems. Work on fundamental research in this area will be carried on in conjunction with the smart loudspeaker project outlined earlier that uses the same expertise.

Yet another new project, this evolving from the work on sound propagation, is concerned with the acoustical properties of porous and fibrous materials and how these are related to the physical parameters describing the microstructure of the material. Theoretical models currently used to describe porous materials involve such parameters as dc flow resistivity, porosity, tortuosity, shape and structure factors. Since these factors cannot always be measured in real materials they are often treated as adjustable constants in fitting measured data. This is a weak link in the justification of the use of specific theories for specific materials. Model porous materials for which the microstructure is known will be used to develop techniques for measuring these parameters. Measurement of the acoustical properties of these materials over a wide range of frequencies then allows the several theoretical approaches to be quantitatively assessed.

The National Research Council is mandated to maintain Canada's basic physical standards and the national standards of various derived quantities. Increasingly commercial contracts, and regulations, are requiring acoustical measurements that are traceable to national standards. To meet these needs the laboratory has a highly accurate microphone comparison system of unique design, and a primary reciprocity calibration system of exceptional stability, environmental control and precision. In an interesting reversal of its role, this latter system has been used as an electroacoustic method for studying the variation of the ratio of specific heats of air with temperature and with humidity, as well as other related physical quantities. The section also has apparatus for the calibration of sensors at frequencies from dc to about 5 Hz and sound pressure levels up to 160 dB. Yet another system is under construction, for the absolute calibration of accelerometers using a laser interferometer for measuring displacement.

The Acoustics Section works closely with national and international standards organizations such as CSA, ANSI, IEC, and ISO. This work relates primarily to the performance and specification of instruments, and especially to factors such as detector characteristics, time constants and weighting functions where it is now clear that allowed tolerances can often lead to variations in measurements that are much greater than would be inferred from the overall instrument specifications. Other standards work is related to measurement methods and prediction schemes.

The Acoustics part of the Section currently consists of seven scientists (A.J. Brammer, G.A. Daigle, T.F.W. Embleton, M.R. Stinson, P. Schuck, F.E. Toole, G.S.K. Wong), three technicians (J.F. Quaroni, R. St. Denis, M.M. Vaillancourt) and five long-term guest workers or visiting scientists, three of whom are working on obtaining higher degrees.

MECHANICAL STANDARDS

As mentioned above the Section maintains the basic mass standard for Canada (the primary mass being a platinum-iridium kilogram), the reference mass standards, and also the primary national standards of pressure and density. These provide legal traceability for regulatory agencies, the Canadian Standards Association, Department of Consumer and Corporate Affairs (remember the local corner store or supermarket), and industries that require acoustical or mechanical standards for national or international trade. This activity includes the development of new analysis and measurement techniques to improve the reliability, ease of traceability and minimization of errors at the shop floor. Primary mass comparisons are made to a precision of about one part in 10^9 . This requires very careful control over environmental factors; temperature affects the dimensional stability of the balance, and temperature and atmospheric pressure affect the difference in buoyancy corrections between masses of different densities.

The national primary standard of pressure is maintained by means of a mercury manometer. Through static expansion systems and pressure balances, any pressure in the range from $10 \mu\text{Pa}$ to 5 MPa can be compared to the primary standard; indirectly pressures can be measured to 150 MPa. (In acoustical terms this is a range of over 260 dB.) Residual gas analysers and ionization gauges are being studied in order to quantify the magnitude of, and understand the reasons for, the variations in these instruments.

The Mechanical Standards part of the Section currently consist of two scientists (A.K. Agarwal, G.D. Chapman) and three technicians (A.H. Bass, D.G. Kearney, L.E. Munro) whose efforts are supplemented from time to time with visiting scientists from the national laboratories of other countries. The most easily identifiable output from the mechanical standards' activities of the Section are calibration reports for numerous clients. Recently we have been assisting certain industrial manufacturers to develop their own standards laboratories, both by giving advice and by the training of their personnel in the ways of precision metrology.

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