APRIL, 1980
Vol. 8, No. 2

# acoustics and noise control in canada

AVRIL, 1980
Vol. 8, Nº 2

# l'acoustique et la lutte antibruit au canada

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Cover design by Rosemary Garsh

**acoustics and noise control in canada**

l'acoustique et la lutte antibruit au canada

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Second Class Mail Registration No. 4692.
Undeliverable copies — return postage guarenteed.

*Nº. d'enregistrement (Poste deuxième classe) 4692.*
*Copies non délivrées: affranchissement de retour est garanti.*

Back issues (when available) may be obtained from the Associate Editor — Subscription and Membership
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Articles in English or French are welcome, and should be addressed to any editor.

*Vous êtes invités à soumettre des articles en français ou en anglais. Prière de les envoyer à un des rédacteurs.*

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## EDITORIAL

It seems only yesterday that the 1979 Annual Meeting was held in Windsor. But planning for the October 1980 Annual Meeting in Montreal is already underway. The Call for Papers published in this issue is a reminder that the convenors are hard at work behind the scenes.

The Annual Meeting has never had a published proceedings. This time, we're taking a small, and very undemanding step in that direction. "Acoustics and Noise Control in Canada" will be printing full-page (400-500 words) abstracts of many of the meeting papers. These will supplement the 50-100 word ones we are used to.

Full-page abstracts will allow authors an opportunity to publish a concise, but detailed record of their talks - which, otherwise, are easily forgotten amid the hustle of Association business and the tedious regimen of the hospitality suites! These long-form abstracts will also be a record for the 50-75% of the membership who do not manage to attend the meeting. The magazine will be enlivened by a series of diverse features - which will paint a fuller picture of the Canadian acoustical scene than our longer, mainline papers allow.

What is required? Only that you take up your pen to write 400-500 words. If you wish, substitute tables and small figures for part of the text. Give your full mailing address. Don't worry about format; we will typeset from any readable submission.

Abstracts will be printed in issues before and after the meeting. For fuller details, see the announcement below. It's a long time to the meeting, or so it seems, but the magazine is ready when you are.

## CAA CALL FOR PAPERS

The Annual Symposium of the Canadian Acoustical Association will be held in Montreal, Quebec on October 22 and 23, 1980 at the Constellation Hotel.

Papers on all aspects of acoustics are invited (including underwater acoustics and vibration).

Abstracts are invited in one of two forms:

(1) Normal 100 words or less for publication in the programme for the symposium. Mail by August 1, 1980 to Cameron Sherry, Domtar Inc., 2001 University St., P. O. Box 6138, Montreal, Quebec H3C 3KV, tel: (514) 282-5306; or

(2) A full-page (~450 word) synopsis for publication in "Acoustics and Noise Control in Canada." Mail as soon as convenient to Daryl May, Wyle Laboratories, 128 Maryland St., El Segundo, California 90245; tel: (213) 322-1763 - and send a copy to Cameron Sherry, address above.

Arrangements for group rates have been made at the Constellation Hotel. Details will be given later.

## CAA: APPEL AUX COMMUNIQUES

Le Symposium Annuel de l'Association Canadienne de l'Acoustique aura lieu à Montréal, Québec le 22 et 23 octobre 1980 à l'hôtel Constellation.

Les communiqués traitant de tous les aspects de l'acoustique sont invités (incluant l'acoustique sous-marine et les vibrations).

Cette année nous demandons des résumés sous une des deux formes suivantes:

(1) Le résumé habituel de 100 mots ou moins pour publication au programme du symposium. Les résumés de 100 mots doivent être remis avant le 1er août 1980 à Cameron Sherry, Domtar Inc., 2001 University St., C.P. 6138, Montréal, Québec H3C 3K4; tél: (514) 282-5306; ou

(2) Une page-résumé (~450 mots) pour publication dans "l'Acoustique et la Lutte Antibruit au Canada." La page-résumé devrait être envoyée aussi tôt que convenable à notre rédacteur, Daryl May, Wyle Laboratories, 128 Maryland St., El Segundo, California 90245; tél: (213) 322-1763 - avec copies à Cameron Sherry, adresse ci-dessus.

Un taux de groupe nous a été offert par l'hôtel Constellation. Les détails seront fournis séparément.

## INTERNATIONAL MEETING IN TORONTO

An international symposium on Personal Hearing Protection in Industry will be held in Toronto, Canada, May 14-16, 1980.

Topics include:

- o Biology of hearing loss
- o Sound measurements and dosimetry
- o Hearing protectors: design and safety
- o Legislation
- o Risks to hearing from sound exposure
- o Economics
- o Quantifying hearing conservation

For further information contact: Office of Continuing Medical Education, University of Toronto, Faculty of Medicine, 245 Fitzgerald Building, Toronto, Ontario M5S 1A8; tel: (416) 978-2718

## REUNION INTERNATIONALE A TORONTO

Un colloque international sur la Protection de l'Audition Personnelle dans l'Industrie aura lieu à Toronto, Canada, le 14-16 mai, 1980.

Parmi des sujets traités, les suivants sont inclus:

- o Biologie de la perte d'audition
- o Mesures de son et de dosage
- o Protecteurs d'audition: conception et sécurité
- o Législation
- o Risques associés a l'exposition sonore
- o Rentabilité
- o Quantification de la conservation auditoire

Renseignements supplementaires: Office of Continuing Medical Education, University of Toronto, Faculty of Medicine, 245 Fitzgerald Building, Toronto, Ontario M5S 1A8; tél: (416) 978-2718.

## NRC ATTACKS MACHINERY NOISE

The National Research Council has recently created an Associate Committee on Machinery Noise. The first meeting of the Committee was held on January 17, 1980 in Ottawa, chaired by Tony Embleton.

NRC Associate Committees are formed from time to time in response to national needs, to study particular problems and advise the Council on solutions.

NRC's new initiative on machinery noise comes at a time of public awareness for both community and industrial noise; the economics of compensation for hearing damage is a factor affecting business and government decisions, and there is widespread federal and provincial legislation to limit workplace noise exposures.

NRC decided that:

o there is a pressing need to produce quiet products to compete in a tough international market that is becoming increasingly hostile as other countries introduce their own noise regulations and produce quieter (or lower vibration) products. Without action, jobs will be lost.

o many companies seem unable to upgrade their products, through lack of appropriate acoustical skills, or seem unaware of the magnitude of the social and economic forces related to noise that face them.

o there could be significant advantages in devising and fostering suitable schemes for exchange between industries faced with noise problems, and universities and government workers with expertise in machinery noise.

## TORONTO CHAPTER INAUGURAL

The CAA now has a Toronto-area local chapter. The inaugural meeting was held in the Ontario Hydro Building in Toronto on February 25, attended by 24 members. Members discussed organizational matters.

The chapter is the result of the initiative of Alberto Behar and Greg Michel, who arranged the meeting after first polling members for their interest. The chapter concept within the CAA has been discussed before - at the 1975 Annual Meeting within the same Ontario Hydro Building for example. At that time, it was decided to let chapters germinate wherever local conditions were right, rather than sow seeds from the central organization. Alberto Behar and Greg Michel have shown that conditions may now be right for a chapter in Toronto. Another has also started in Ottawa.

Meetings are planned each quarter, probably on Monday evenings. Some will be "dinner meetings," and some may occasionally be elsewhere in Southern Ontario. Program items have yet to be settled. A meeting is planned for May, however, at which time it may be possible to entice speakers from abroad who will be visiting Toronto then. (See "International Meeting in Toronto," this section.)

A Steering Committee has been set up to guide the Toronto Chapter. As well as Alberto Behar and Greg Michel, it includes Sharon Abel, John Bradley, Graham Higgott, Chris Krajewski, John Swallow and Winston Sydenborgh. This is a broad-based committee with membership from industry, consultancy, instrumentation suppliers, university, government and medicine. John Manuel brought greetings from the CAA President, Tom Northwood - and a reminder that chapters should not expect CAA funding for their activities!

Forthcoming Toronto Chapter events will be announced in "Acoustics and Noise Control in Canada." We hope to convey news of other chapters too.

## ENVIRONMENT ONTARIO REPORTS

The Noise Pollution Control Section of Environment Ontario received 448 new noise complaints in 1978-79. Complaints of excessive noise from industry resulted in 165 investigations, and two persistent offenders were prosecuted. A fine of $2,500 was assessed in one case, the other is pending. The Section also investigated 95 complaints of air conditioner noise, 73 complaints of blasting concussion noise, and 115 other complaints of miscellaneous noise activities. Provincial officers were called upon to provide expert testimony in 12 actions launched by various municipal and private parties.

The final report of the Model Municipal Noise Control By-law was published in August 1978. Thirty municipalities, accounting for more than 30% of Ontario's urban population, have adopted noise control by-laws under Section 95a of The Environmental Protection Act. Twenty additional by-laws were being prepared for submission to the Minister of the Environment for his approval.

The fourth year of the Environmental Acoustics Technology training program sponsored by the Ministry was successfully completed. An external contract has been awarded to provide a draft Acoustics IV training manual, the final text in the planned series of training materials.

The Noise Pollution Control Section has provided technical comment on more than 2,000 new land-use proposals and industrial projects in the four years since the noise impact assessment program was formalized. Increasing attention has been given to assessing class environmental impact statements, inter-government studies on transportation noise problems, and use of lands subject to Ministerial zoning orders.

The Section sponsored and guided the following major research projects: a study of the effects of transportation noise (funded by the Provincial Lottery Trust Fund); an investigation of noise emissions from a railway marshalling yard (funded by the Transportation Development Agency of Transport Canada); a study of community response to railway noise (funded by Experience '78). The United States Environmental Protection Agency used data from the last study in proposing U. S. Railroad Noise regulations. Two other noise-related projects were funded under the Ministry Experience '78 program. Both were external study projects on transportation noise and were awarded to two Ontario universities. Staf also cooperated in the report "Noise in the Human Environment" prepared by members of the Canadian Acoustical Association for the Environment Council of Alberta.

## NEW RESEARCH CONTRACTS

Bill Bradley reports on the latest research contracts awarded by the federal government.

To University of Saskatchewan, Saskatoon (Dr. D. Dodds and Dr. G. Wacker), $2,000 for an initial phase of a study concerning "Subjective Evaluation of Delta Codes in Quality Music and Sound Broadcast Distribution." Awarded by the Dept. of Communication.

To Nova Scotia Technical College, Halifax, $23,995 to "Design and Build a System to Monitor, by means of Ultrasonic Telemetry, Temperature and Salinity at Gear and Depth of Gear Towed behind the E. E. Prince or Similar Vessel." Awarded by the Dept. of Fisheries and Oceans.

To Memorial University of Newfoundland, St. John's (Dr. M. J. Clouter and Dr. H. Kiefte), $8,055 to "Determine the Acoustic Properties of Methane Hydrate by Brillouin Spectroscopy." Awarded by the Dept. of Energy, Mines and Resources.

To Dalhousie University, Halifax (Dr. H. W. Jones), $35,135 for a "Study to Design Apparatus for the Ultrasonic Inspection of Turbine Blades." Awarded by the Dept. of National Defence.

To Huntec ('70) Ltd., Scarborough, $49,000 for a "Study of the Normal Incidence Reflection, and Scattering of a Deep Towed System (DTS) Acoustic Signals from the Sea Floor." Awarded by the Dept. of National Defence.

To Huntec (70') Ltd., Scarborough, $26,830 for an "Evaluation of Sonar Equipment and Techniques for Applications in the Beaufort Sea." Awarded by the Dept. of Fisheries and Oceans.

To Institut national de la recherche scientifique, University of Quebec, Verdun, $14,815 for "Use of Voice Signal Digital Compression Techniques in Satellite Telecommunications Systems." Awarded by the Dept. of Communications.

To the University of Winnipeg (Dr. C. W. Bell), $50,870 for "Collection and Analysis of Wind and Temperature Data to Evaluate and Develop Vertical Wind Field Prediction Models." Awarded by the Dept. of the Environment.

To Mesotech Systems Ltd., North Vancouver, B.C., $21,536 for "Development of a Wide Swath Sonar System - Phase I." Awarded by the Dept. of Fisheries and Oceans.

To Huntec ('70) Ltd., Scarborough, $247,703 for "Development of a Non-Linear Acoustic Transducer for Through the Ice Echo Sounding Systems for Hydrographic Charting in the Arctic." Awarded by the Dept. of Fisheries and Oceans.

To Hermes Electronics Ltd., Dartmouth, Nova Scotia, $1,000 to "Troubleshoot the Remote Acoustic Data Acquisition System." Awarded by the Dept. of National Defence.

## NEW FRENCH NOISE BULLETIN

The French Ministry of the Environment now publishes a bimonthly bulletin on acoustics. Each issue contains a review of 200 books and articles. The bulletin also publishes noise news.

A great deal of the bulletin's material is of North American and British origin. The bulletin may therefore be useful in giving French Canadian acousticians access in French to a large body of local as well as international acoustical literature.

For further information, please contact Monsieur X. Dagallier, Centre d'Information et de Documentation sur le Bruit, 23, rue de Madrid, 75008 Paris, France.

## NOUVEAU BULLETIN FRANCAIS SUR LE BRUIT

Le Ministère de l'Environnement de France publie maintenant un bulletin bimensuel sur l'acoustique. Chaque numéro contient des critiques de 200 livres et articles, on trouve également des nouvelles relatives au bruit.

Un grande partie du contenu de bulletin provient de l'Amérique du Nord et de la Grande Bretagne. Ce bulletin intéresserait particulièrement des acousticiens francophones, il leur offre en français des publications nationales et internationales sur l'acoustique.

Pour plus de renseignements, s'addresser à: Monsieur X. Dagallier, Centre d'Information et de Documentation sur le Bruit, 23, rue de Madrid, 75008 Paris, France.

## ASA MEETS

The next meeting of the Acoustical Society of America is on April 21-25 1980 at the Colony Square Hotel, Atlanta, Georgia.

National Research Council Canada / Conseil national de recherches Canada
Acoustics Section
Division of Physics

Health and Welfare Canada / Santé et Bien-être social Canada
Non-Ionizing Radiation Section,
Radiation Protection Bureau
Environmental Health Directorate

invite you to an industry-oriented information

SEMINAR

on

# OCCUPATIONAL EXPOSURE TO NOISE AND VIBRATION

## - EFFECTS, MEASUREMENT AND CONTROL

DATE: October 20-21, 1980 LOCATION: Constellation Hotel, MONTREAL

DESIGNED FOR acousticians, engineers, industrial hygienists and others concerned with occupational health and safety.

SUBJECTS for LECTURES and DISCUSSION include:

- NOISE. Review of effects on people and their relation to noise exposure; regulation of occupational noise exposure in Canada with implications for employers and employees; patterns of noise exposure and hearing loss in Canadian industry; techniques for and problems of measuring noise exposure in factories, outdoors and near people, and treatment of intermittent exposure and impulse noise.

- WORKSHOP on the problems of in-plant noise control (subjects to be chosen by participants)

- VIBRATING HAND-HELD TOOLS. Review of symptoms and objective tests for "white finger"; survey of use of vibrating tools in Canadian industry; experimental techniques for and problems of measuring hand-transmitted vibration; relations between exposure to vibration and development of symptoms; tolerable vibration exposures; control of occupational exposure to vibration.

TO REGISTER contact Mrs. D.A. Benwell, Room 233, Environmental Health Centre, Tunney's Pasture, Ottawa, Ont. K1A 0L2. Tel: (613)995-9801. Register now as REGISTRATION IS LIMITED TO 150 PERSONS.

SEMINAR FEE: $60 ($80 after August 15, 1980), includes copy of lectures and morning and afternoon coffee.

NOTE: The seminar is immediately prior to and in the same location as the CANADIAN ACOUSTICAL ASSOCIATION'S ANNUAL MEETING.

# A REVIEW OF ULTRASOUND APPLICATIONS

by

D.A. Benwell
Non-Ionizing Radiation Section
Radiation Protection Bureau
Health and Welfare Canada
Ottawa, Ontario

ABSTRACT

A brief history of early applications of ultrasound is given together with an overview of the diverse applications of ultrasound today. Ultrasound is defined and its properties are compared with those of sound.

## 1. Background

In 1883 Galton[1] designed a whistle for the production of sounds near or above the upper limits of human hearing. However, the first practical and for many years the only application of ultrasound was in sonar for the detection of submarines. The device, first produced by Paul Langevin in 1917[2], used a quartz crystal vibrating at 50 kHz to produce an ultrasound beam which was propagated into water and the reflected beam detected. During World War II the same principle was used for an ultrasound detecting device. The device was mounted on the sides of torpedoes and the sound from ships or submarines caused the torpedoes to be directed towards them. The first industrial application of ulrasound was an ultrasonic flaw detection system, later known as an "inspectoscope". This was developed between 1939 and 1945[3,4]. This system was used for locating flaws in materials and for measuring the thickness of materials for which only one face was available.

World War II was the catalyst for the rapid development of pulse techniques in radar and sonar, and this in turn led to the preference of pulse techniques over continuous waves in the detection of material defects. Ultrasonic non-destructive testing has steadily increased in efficiency and become more sophisticated. Improved ultrasonic non-destructive testing techniques have influenced the applications of ultrasonics to medicine.

One of the early technological advances aiding the development of ultrasound was the introduction in 1945 of ferroelectrics (materials with a natural polarization), that could be obtained in ceramic form. Up to that time the principle transducer materials were quartz crystals, ADP crystals, and magnetostrictive materials.

## 2. What is Ultrasound?

Ultrasound is a form of mechanical energy having frequencies above the normal hearing range (> 20 kHz). As a form of acoustic radiation, ultrasound obeys the basic principles of sound propagation. In addition, ultrasound's high frequency (and thus short wavelength), results in it conforming more closely than sound to the basic principles of light propagation.

The differences between ultrasound and sound terminology are due to the following major factors. Since ultrasound frequencies do not act upon the ear in such a way as to produce the sensation of sound, the reference level of minimum audible intensity adopted in the definition of sound pressure level (dB), has little meaning. The ultrasound quantity used instead is ultrasound intensity. As in sound, ultrasound intensity is defined as the rate of flow of ultrasound energy through a unit of area, and is measured in watts per square centimetre. Airborne ultrasound is the only form of ultrasound commonly measured in terms of decibels. This is mainly due to airborne ultrasound frequencies being in the range of 20-40 kHz, immediately above the upper sound frequencies. Although these frequencies are inaudible, it has not been confirmed that they have no effect on the hearing mechanism. In addition some airborne ultrasound applications generate audible subharmonics. The majority of applications of ultrasound are, however, based on its propagation in liquids or solids. This results in a corresponding change in basic constants such as the speed of sound with respect to sound and other airborne acoustic radiation. Finally, since many applications of ultrasound are based on the emission of a signal (such as a short pulse) and the reception of its echo, factors such as beam width and pulse duration are important, as are the spatial and temporal, peak and average, intensities of the ultrasound pulse. For more detailed information on ultrasound terminology, the American Institute of Ultrasound in Medicine has produced an interim standard, is shortly to be published in their magazine "Reflections".

## 3. Medical Applications

Ultrasound has a variety of medical applications, the most common being as an aid to healing in therapy treatments. The most rapidly expanding medical use is as a diagnostic tool, partly due to the commonly held belief that there is no risk from ultrasound. It does appear to provide much less risk than X-radiation as a diagnostic tool. In addition ultrasound has surgical, dental and other applications.

### 3.1 Diagnosis

Ultrasound was introduced to diagnostic medicine in the mid 1950s and ever since has been growing at such a rate that it has been stated[5] that "with expanding services in ultrasound diagnosis, the frequency of human exposure is increasing with the potential that essentially the entire population may be exposed." The Bureau of Radiological Health (U.S. Department of Health, Education and Welfare) estimates that by the early 1980s, every pregnant woman will undergo at least one ultrasound examination of the fetus. Certainly the sales of diagnostic ultrasound devices have been increasing rapidly over the last 10 years, and are projected to double between 1980 and 1983[6]. In addition, new techniques continue to be developed. Ultrasonic spectroscopy, time delay spectrometry and holographic techniques all offer new potential for this already expanding imaging modality.

Most diagnostic ultrasound equipment uses the pulse-echo measurement technique. The transmitter is an electronic circuit that produces a very short electrical pulse. A characteristic number of pulses per second cause the piezoelectric crystal to vibrate at its resonant frequency and thus to generate pulses of ultrasound. The returning echo is received by the transducer (usually the same piezoelectric crystal as was used to produce the transmitted ultrasound pulse), the ultrasound wave energy causing a mechanical distortion in the crystal and generating an electrical impulse or signal. This electrical signal is processed by another electronic circuit, called the receiver, which amplifies, rectifies and demodulates the electrical echo signal. The resultant signal is then displayed on the A-mode display (oscilloscope).

The A-mode (amplitude modulation), is the oldest and simplest method of displaying pulse-echo information. The horizontal axis on the display represents time or depth into the patient, the vertical axis represents the logarithm of the echo amplitude. A-mode displays are used mainly for echo-encephalography, soft-tissue biopsy and some ophthalmologic examinations.

All other pulse-echo displays are based on the B-Mode (Brightness modulation). In B-mode a small cross-section of the patient is displayed on the screen, the brightness, or shade of gray, representing the amplitude of the echoes. This is modified in the M-mode (time-motion mode), by a constant velocity sweep of the display to enable the motion of moving reflectors in the body to be measured. In the B-scan an articulated arm is attached to the transducer enabling position and angulation to be constantly monitored. As the transducer scans the patient, the B-mode and position information enable a 2-dimensional image to be generated. This is the most frequently used display today. However more sophisticated displays have been developed. One of these relies heavily on television and scan converter technology to produce a Grey-Scale, which, as the name indicates, gives images where the echo amplitude strengths are displayed in shades of grey. Another is the Real-Time Display, which displays images (generally grey-scale) at rates up to 30 frames a second. Real-Time displays are invaluable in cardiac and fetal monitoring studies.

In addition to pulse-echo techniques there are many applications for continuous-wave (cw) beams of sound in diagnosis. For example cw techniques are useful for measuring the change in frequency of the echo from that of the transmitted beam. By use of the Doppler shift principle the velocity of the reflectors may be ascertained. The transducer for Doppler studies is made up of two crystals, a transmitter and a receiver. The echo received is modulated by leakage from the transmitting crystal in the transducer. The beat frequency of these two signals is the Doppler frequency. The Doppler (beat) frequency is detected (by filters), amplified, and usually made into an audible sound. The higher the velocity of the reflector, the higher the pitch (frequency) of the audible sound produced.

The significance, or clinical usefulness, of diagnostic applications of ultrasound has been summarized by Lyons[7] as shown in Table 1. He has graded the significance of clinical usefulness of diagnostic ultrasound procedures as shown below:

Clinical Significance

* Limited significance
** Useful ancillary investigation
*** Most efficacious, non-invasive examination
**** Sole investigative tool.

Table 1. Diagnostic Ultrasound Examinations and their Clinical Significance with respect to Other Imaging Modalities (adapted from Lyons[7]).

| Body Part | Organ | Examination | Clinical Significance |
|---|---|---|---|
| Head | Brain | Midline determination | * |
| | | Ventricular size (newborn) | ** |
| | Eyes | Eyeball - axial length | ** |
| | | - foreign body | * |
| | | - retinal detachment | *** |
| | | - mass evaluation | ** |
| | | Orbit - proptosis | * |
| Neck | Thyroid | Mass evaluation | ** |
| | | Carotid artery | * |
| | | Potency evaluation | * |
| Chest | Heart | Pericardial effusion | *** |
| | | Valve investigation | *** |
| | | Wall evaluation (motion thickness) | *** |
| | | Chamber size, function | *** |
| | | Tumour detection | *** |
| | Pleural space | Effusion localization | * |
| | Breast | Mass evaluation | * |
| Abdomen | Liver ) | Evaluation size, | *** |
| | Kidneys ) | parenchyma and | *** |
| | Pancreas) | associated masses | *** |
| | Spleen ) | | *** |
| | Biliary Tract | Gallbladder stone detection | *** |
| | | Duct size | ** |
| | Aorta | Aneurysmal dilation | *** |
| | Lymph Nodes | Evaluation | ** |
| | Perito-neal space | Ascites and abscess detection | *** |
| Pelvis | Uterus (pregnant) | Evaluation - fetus | **** |
| | | - placenta | **** |
| | | - amniotic cavity | **** |
| | Uterus (non-preg-nant) | Mass size determination | ** |
| | Fallopian | Mass evaluation | *** |
| | Ovaries | Mass evaluation | *** |
| | Bladder | Tumour assessment | * |
| | Prostate ) Scrotum ) | Tumour detection | * |
| Extremities | Arteries and veins | Potency evaluation | * |

## 3.2 Therapy

Ultrasound therapy has been used for over 40 years in physiotherapy. It usually involves the application of a hand-held ultrasound transducer to the injured area of a patient, and treating using either a continuous or pulsed beam. The transducer head is generally moved over the area of injury to obtain as uniform a treatment distribution as possible. Coupling the transducer to the treatment area may be achieved by[8]:

(i) treating within a waterbath,
(ii) holding the transducer in contact with the skin using a coupling medium (film of mineral oil, glycerine or aqueous gel) to exclude the air, or
(iii) application through a water-filled rubber or plastic balloon containing water.

The choice of coupling media appears to be important since the energy transmitted by coupling agents in common use appears to vary[9], although Warren et al[10] claim that the difference in transmissivity is only about ±10%.

The objective of ultrasound therapy appears to be to stimulate the blood flow within the injured region, which it appears to do effectively[11], and to provide deep heating to muscles and other tissues. Summer and Patrick[8] claim that the efficacy of ultrasonic therapy is achieved by four specific effects:

(i) Thermal - a temperature rise within the tissue which is proportional to the input power and exposure time. Ultrasound seems to have the advantage that it is absorbed more in muscle than fatty tissue.
(ii) Micromassage - caused by the mechanical reactions of the ultrasound in tissue, such as compressions and dilations.
(iii) Volume reduction - as the ultrasound wave passes through the tissue it produces instantaneous small reductions in volume which are independent of frequency but proportional to the intensity.
(iv) Motion and amplitude - pressure waves set up stress patterns in tissue, producing reciprocal movement of cells.

Lehmann et al[12,13] point out that the main therapeutic value of ultrasound is related to its selectivity of absorption - in soft tissue this absorption is directly related to the protein content of the tissue[14]. Lehmann et al claim that the benefit of ultrasound as a therapeutic agent is that it heats selectively the areas that one requires to be heated, including such areas as superficial bone, scar tissue within soft tissue, tendons and tendon sheaths, etc. Further, that the ultrasound may accelerate the diffusion process across biologic membranes, implying an increased rate of healing.

Although the biological mechanisms of ultrasound therapy have not received systematic investigation, it seems likely that its value lies in the unique heating distribution it provides. There also appears to be some evidence for low-intensity ultrasound induced non-thermal effects which may be important in certain physio-therapeutic applications as the breakdown of fibrous adhesions at the site of an operative incision[15,16].

It is, however, very difficult to assess the benefit of ultrasound therapy, as Roman[17] found. 100 patients were treated or sham irradiated for lower back pain, bursitis of the shoulder and myalgia. Sixty percent of the patients receiving ultrasound were categorized as good or normal, but 72.1% of the unirradiated were in the same category.

Therapy devices have recently been the subject of extensive investigations, both in the United States and Canada[18]. A common conclusion of these surveys has been that most ultrasound therapy devices were not delivering the "dose" prescribed for the patients, errors in measured/indicated acoustic output were found up to ±200%. This has led to federal regulations for ultrasound therapy devices being proposed.

## 3.3 Surgery

Although ultrasound applications in surgery are highly specialized, they cover a wide range of uses, including the following: the production of lesions in neurosurgery to alter the tissue function at a site in the brain without the disruption of intervening tissue[19], an ultrasonic drill for cleaning blood vessels[20]; the destruction and removal of blood clots[21], gallstones[22] and kidney stones[23]; a vibrating scalpel for cutting biological tissues; as an aid in bone welding[24] and acupuncture[25]. A highly specialized technique, which has become routine in North America for ocular surgery is the phaco-emulsification and aspiration technique for the removal of cataracts[26]. Basically the ultrasound is applied through a hollow titanium needle, the ultrasound breaks up the cataract and the broken pieces are sucked up through the needle.

However, probably the most successful surgical application of ultrasound has been in vestibular surgery for Menière's disease. This disease is due to a disorder of the vestibular end organ which results in attacks of vertigo of varying duration and severity. Treatment involves surgically exposing the lateral semicircular canal and directly applying 3 MHz ultrasound for about 20 minutes. The ultrasound probe tip is placed in contact with the bone over the canal while normal saline flows continuously to provide good coupling. Clinical results indicate that vertigo is abolished in 75%-85% of patients[27].

## 3.4 Dental

The ultrasonic drill was developed in the early 1960s but never really gained acceptance in dentistry due to the introduction of the high speed rotary drill. However, a number of other applications of ultrasound in dentistry have been steadily growing[28]. These include: cleaning and calculus removal, gingivectomy, root canal reaming, orthodontic filing, amalgam packing and gold foil manipulation. Conventional techniques for these tasks are fairly satisfactory, but there is no doubt that the silence and ease of the ultrasonic method relieves the patient of the stress associated with dental treatment. Frost[29], in 1977, estimated that there may be as many as 100,000 ultrasonic units used in U.S. dental offices for scaling of teeth and periodontal care. However, the cost of this equipment and the general lack of knowledge and training concerning its use, have been responsible for the scarcity of ultrasonic dental instruments in most other parts of the world.

The cavitation effect of ultrasound is used in dentistry for its cleaning power which goes to work on the gums and teeth and their many interproximal crevices. Additionally, ultrasonic massage of gingival tissue assists penetration of antiseptics and other medicines.

3.5 Other Medical Applications

These include ultrasound atomizers[30] (aerosols, nebulizers), where high intensity ultrasound is beamed through a liquid towards an air interface producing a fine dense fog, and gas bubble detection[31] using Doppler ultrasound techniques.

## 4. Domestic Applications

There are an ever increasing number of consumer-oriented devices being manufactured using ultrasound. Examples of these are quartz clocks, garage door openers, T.V. channel selectors, remote controls, burglar alarms, dog whistles, bird and rodent scarers and traffic control devices. A recent application is use of ultrasound for range-finding on Polaroid cameras. In general, these applications employ low intensities and frequencies at the lower end of the ultrasound range (20-100 kHz). Ultrasound, for these applications, is usually propagated in the air, so that the beam is rapidly attenuated over short distances.

## 5. Industrial and Commercial Applications

Industrial and commercial applications of ultrasound have been reviewed in a number of reports[32, 33, 34]. Generally these applications can be divided into two categories, high and low power, depending on the power or intensity levels involved. Applications employing higher powers generally rely on compound vibration-induced phenomena occurring in the object or material irradiated. These phenomena include: cavitation and microstreaming in liquids, heating and fatiguing in solids, and the induction of surface instability at liquid-liquid and liquid-gas interfaces. Some of the more common applications of high power ultrasound are shown in Table 2. This table also provides a description of the application and the ultrasound frequency and power or intensity range used, where these parameters are known. One notes that the most practical frequency range for these applications is 20-60 kHz. Most industrial ultrasound is produced using electrostrictive or magnetostrictive transducers[33], where the elements change their physical dimensions in response to an applied electric or magnetic field.

Probably the oldest industrial application is cleaning via cavitation and microstreaming mechanisms. Most cleaning tanks operate at intensities up to 10 W/cm$^2$, although 2 W/cm$^2$ is more commonly used. Frequencies are usually between 20-50 kHz. Substantial noise levels are produced by this application due to the violently cavitating liquid.

Plastic welding has become popular in the last 10-15 years, where ultrasound is used in the assembly of toys, appliances, thermoplastic parts. High frequency (above 20 kHz) vibrations at intensities of greater than 20 W/cm$^2$ produce sufficient heat to melt the plastics at the required locations. The principle advantages of this method are speed, cleanliness, ease of automation, and welds can be accomplished in normally inaccessible places. An interesting recent application is the ultrasonic sewing machine. Here woven or non-woven fibres can be "sewn" together without thread.

Table 2. Low Power Applications of Ultrasound in Industry. Adapted from Lynnworth (32).

| Application | Principle | Frequency |
|---|---|---|
| Flowmetry | Determining flow rates for gases, liquids and solids - Doppler technique | 1 - 10 MHz |
| Elastic Properties | Relating speed of sound to modes of polerization | 25 - 150 kHz |
| Thermometry | Response to temperature dependence of sound speed or attenuation | Up to 30 MHz |
| Thickness | Timing round trip interval of beam | 2 - 10 MHz |
| Density, Porosity | Resonant and non-resonant probe transmission | - |
| Grain size of metals | Ultrasound attenuation | few MHz |
| Pressure | Frequency of quartz crystal resonator changes with applied pressure | 0.5 - 1 MHz |
| Gas leaks | Detection of ultrasonic "noise" | 36 - 44 kHz |
| Level | Attenuation of ultrasound beam - pulse-echo technique | around 100 kHz |
| Counting | Beam interruptions counted | 40 kHz |
| Flaw detection | Observe discontinuities in reflected beam | 25 kHz to 25 MHz (mW powers) |
| Delay lines | Transform electric signal into ultrasound and back again after ultrasound has travelled a well-defined path. | - |
| Burglar Alarms | Ultrasound beamed into room and a certain level of re-flected beam is monitored. If this level changes (with intruder) alarm sounds | 18 - 50 kHz (mW powers) |
| Pest Control | Frequency and intensity of ultrasound bothersome to pests - inaudible to humans | 18 - 50 kHz (mW powers) |
| Sonar | Doppler method determines velocity of object | 5 - 50 kHz |
| Acoustic Microscope | Observe phase shift and at-tenuation of ultrasound beam by the specimen. | Hundreds of MHz |

Table 3. Industrial Applications of High Power Ultrasound.

| Application | Description | Frequency kHz | Power or Intensity Range |
|---|---|---|---|
| Cleaning and degreasing | Cavitated cleaning solution scrubs parts | 18 - 100 | Usually below 10 W/cm$^2$ but up to 100W power |
| Soldering and braising | Displacement of oxide film to acomplish bonding without flux | Around 30 | 2 - 200 W/cm$^2$ |
| Plastic welding | Welding soft and rigid plastic | 20-60 | Usually 20 - 30 W/cm$^2$ but power below 1000W output |
| Metal welding | Welding similar/ dissimilar metals | 10-60 | Up to 10,000 W/cm$^2$ |
| Machining | Rotary machining, impact grinding using abrasive slurry, vibration assisted drilling | Usually 20 | - |
| Extraction | Extracting perfume, juices, chemicals from flowers, fruits, plants | Around 20 | About 500 W/cm$^2$ |
| Atomization | Fuel atomization to improve combustion efficiency and reduce pollution; also dispersion of molten metals | 20 - 30 000 | Up to 800W |
| Emulsification, dispersion, and homogenization | Mixing and homogenizing of liquids, slurries, creams | - | - |
| Defoaming and degassing | Separation of foam and gas from liquid, reducing gas and foam content | - | - |
| Foaming of beverages | Displacing air by foam in bottles or containers prior to capping | | |
| Electroplating | Increases plating rates and produces denser, more uniform deposit | Around 27 | 30W |
| Erosion | Cavitation erosion testing, deburring, stripping | - | - |
| Drying | Drying heat sensitive powders, food-stuff, pharmaceuticals | - | - |
| Cutting | Cutting small holes in ceramics, glass and semi-conductors | Around 20 | About 150W |

Metal welding was introduced commercially in the late 1950s in the semiconductor industry for welding or microbonding miniature conductors. The process involves relatively low temperatures, usually below the melting point of the metal. The welding depends on ultrasonic cleaning. The ultrasound causes mutual abrasion of the two surfaces so that exposed plasticized or metal surfaces can be joined under pressure to form a "solid-state" bond. For this process, very high power densities are needed at the welding tip - of the order of 2000 W/cm$^2$ at a frequency between 40-60 kHz.

Ultrasound soldering, without fluxes, has also been carried out since the early 1950s. Cavitation in molten solder erodes the surface of metal oxides and exposes the clean metal to the solder so that simultaneous cleaning and tinning of the metal can be effected. The ultrasonic intensities used are up to 100 W/cm$^2$ at frequencies between 20-50 kHz.

Machining of metals can be carried out using an abrasive slurry between the vibrating tool and the workpiece. Using a rotary machine and an axial ultrasonic vibration, one can machine using diamond impregnated core bits.

Ultrasonic cavitation provides a more rapid cutting action for water cooled core bits. Typically these devices operate at 20 kHz.

In high power applications, the materials being worked are physically changed. This is in contrast to low power applications where the ultrasound is used to examine rather than alter materials. In many cases, these low power applications involve frequencies in the megahertz range as shown in Table 3. Applications not shown in this table include the determination of viscosity transport properties, position phase, thickness, composition, anisotropy and texture from size, stress and strain elastic properties, bubbles, particle and leak detection, non-destructive testing, acoustic emission, imaging and holography, and counting via beam disruption. Much of the equipment used in these applications has intrusive ultrasonic probes, but non-invasive, externally mounted transducers are also used involving both pulsed and resonance techniques.

## 6. Summary

Ultrasound devices are now used in many fields. In recent years, with the great technological advances that have occurred, there has been significant growth in the number and diversity of ultrasound applications. Figure 1 summarizes the variety of ultrasound devices and applications in use today, an impressive list when considering that the earliest recorded ultrasound source was invented less than 100 years ago. Today the fastest growing ultrasound application is that of diagnostic medicine, although ultrasound applications continue to increase in numbers and usefulness in many areas of industry and medicine.

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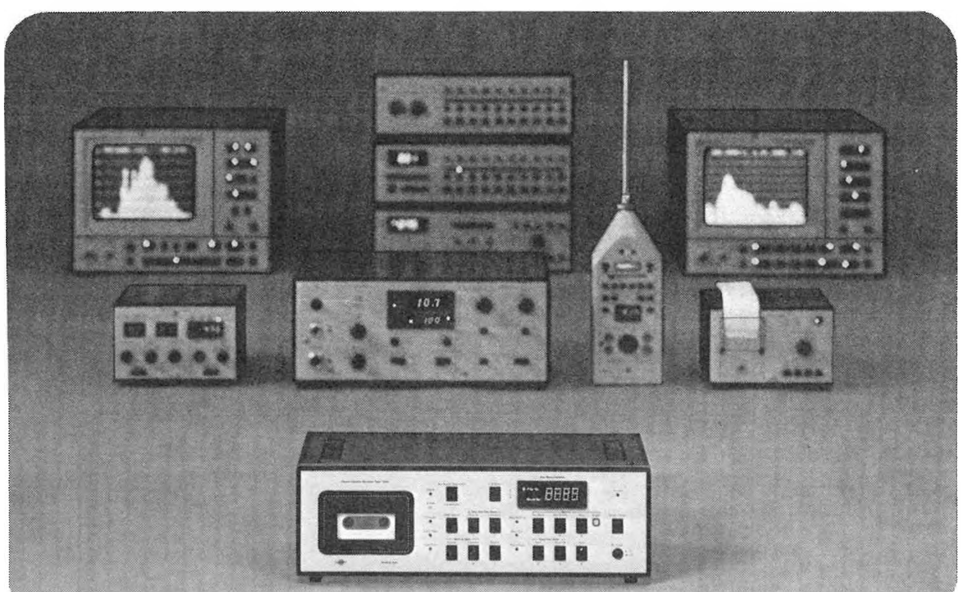

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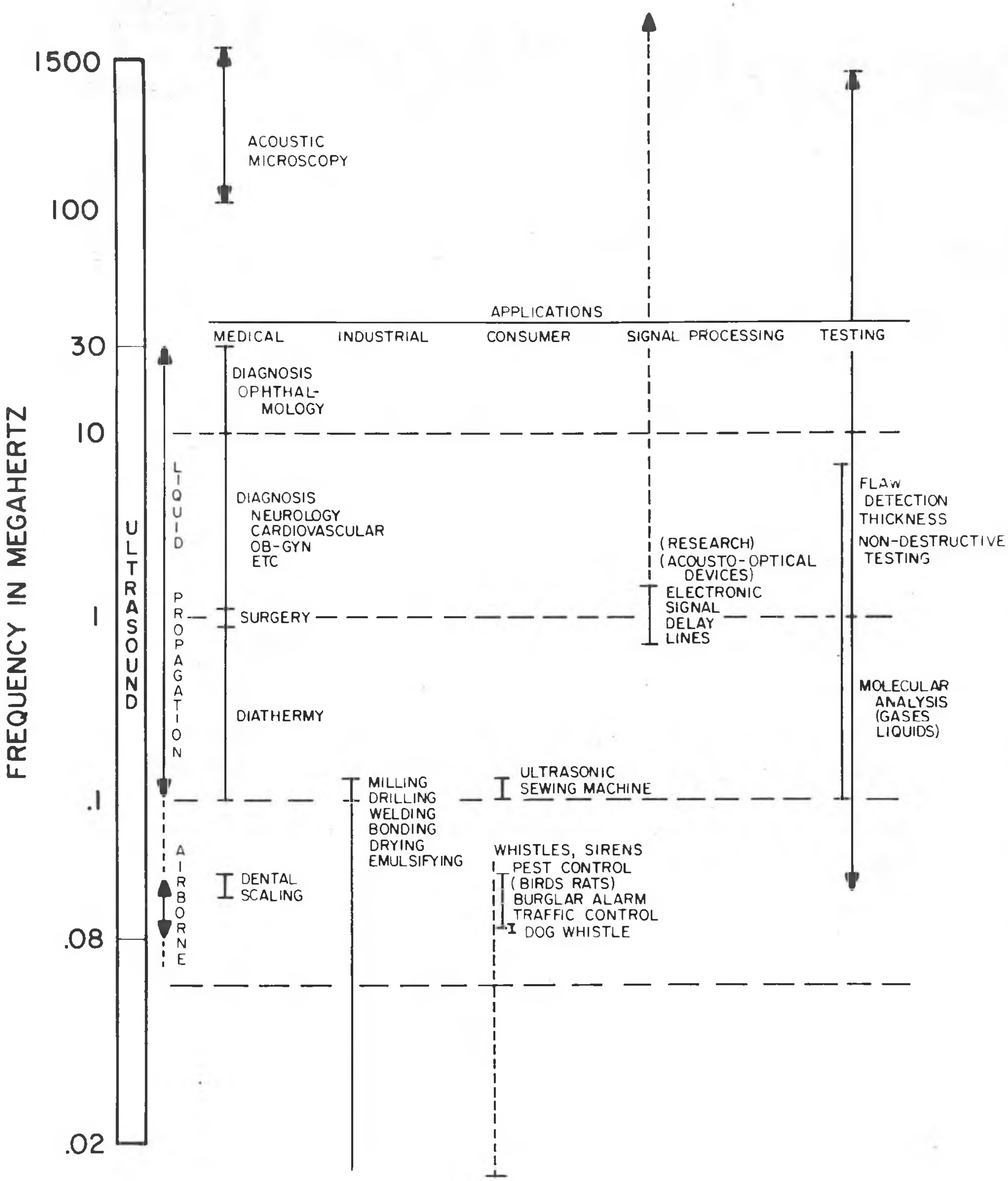
Figure 1. Ultrasound Applications (adapted from Reference 5).



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# SOUND LEVELS AND NOISE EXPOSURE IN TWO ONTARIO GENERATING STATIONS

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ABSTRACT

A study of sound levels throughout two fossil fired generating stations, and the noise exposure to staff, was carried out to evaluate the noise hazard and to establish the relative importance of various equipment in the noise doses incurred.

Ontario Hydro has carried out a study of sound levels and noise exposure levels in two of its thermal generating stations: Lakeview, an older station to the west of Toronto;and Nanticoke, a large modern thermal station on the shore of Lake Erie. The study was carried out jointly by the Health and Safety Division and the Power Equipment Department, with the two objectives of

(i) determining the levels of noise exposure in various job classifications, and

(ii) determining the equipment most responsible for the noise exposure, particularly with a view to the design of new stations.

The various workers and teams were accompanied on the job by junior engineers equipped with sound level meters, and the time spent in specific areas was noted as well as the sound levels there. At the same time a detailed sound level map was plotted for the whole station and sound pressure level spectra taken for locations where particular items of equipment were predominant.

Noise dosimeters were discarded after some initial attempts as these gave some rather erratic results and could not, of course, identify the source of noise causing the exposure to a quite mobile worker.

The major conclusions of the study are that mechanical maintenance staff had the highest noise dose and that the doses at Lakeview were higher than at Nanticoke. Most of the exposure is the result of working on the ground floor of the Station. Noise from the motor driven boiler feed pumps at Lakeview was a major contributing factor to employee

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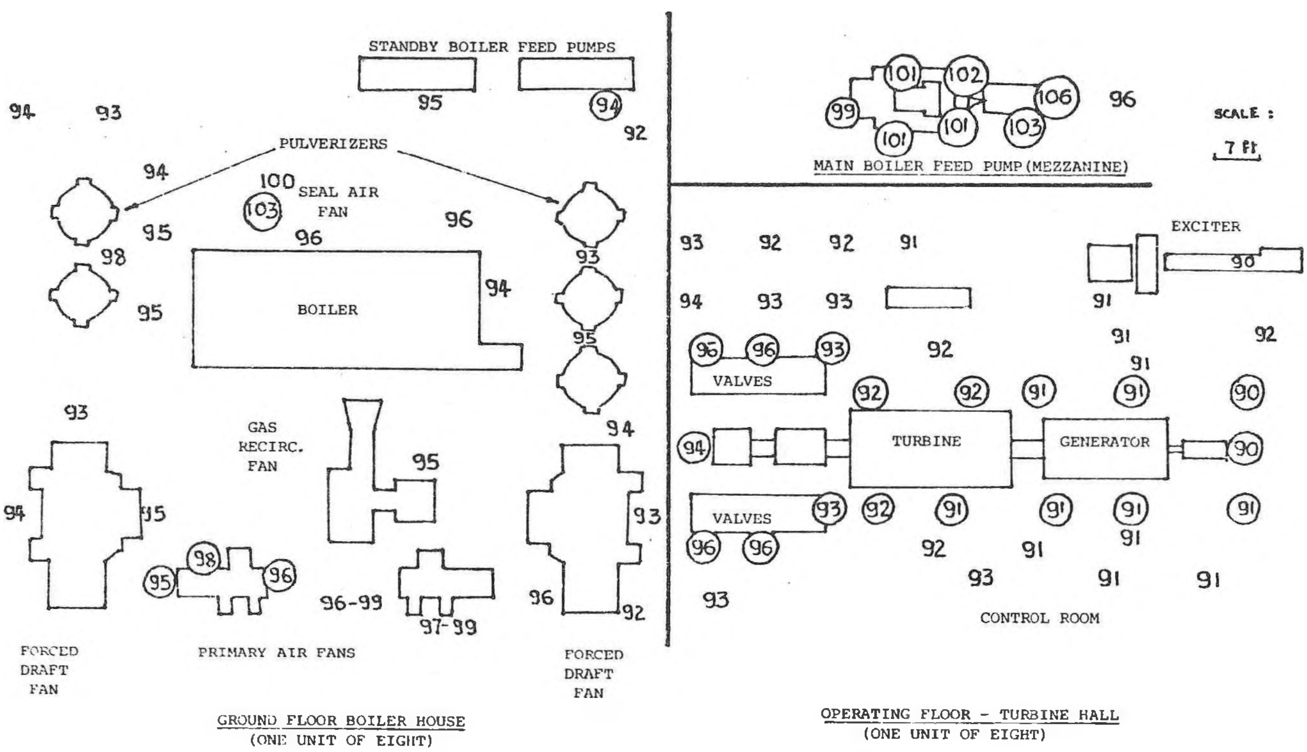
noise dose. Although the steam turbine driven boiler feed pumps at Nanticoke are noisy (see map) they are located on a less travelled mezzanine floor.

It would require a reduction of approximately 7 dBA on the ground floor at Lakeview and 5 dBA at Nanticoke to result in a noise dose lower than 85 dBA for an 8h equivalent shift (OSHA system) without hearing protection.

The centrepiece of the Generation Station, the Turbine Hall, does not produce a major contribution to noise exposure. Most exposure here is to maintenance staff when working on a "down" unit while the others are still running. Sound levels are in the mid and upper 80's dBA around the down unit. The turbine halls are extremely reverberent: 2-4 dBA variation throughout. Acoustical treatment of the walls as has been done in Belgium and the US is being considered for future stations with a view to reducing the exposure obtained here rather than enclosing the turbine generator set, which is extremely costly and rather impractical.

Noise-thermal enclosures are planned for future boiler feed pumps and wrappings for the very large boiler fans and ductwork to reduce noise exposure on the ground floor. New coal pulverizers are expected to be about 7 dBA quieter than the ones measured here. Sound level criteria form part of the specifications for pumps and motors but to this date very little design effort has been expended by manufacturers to produce quiet pumps except for military application.




Nanticoke Generating Station
A-weighted sound levels: circled numbers at 1 m from machine surface outline, other numbers at shown locations; microphone height at all locations, 1.2 m

# EFFECT OF STOPLIGHTS ON TRAFFIC NOISE

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ABSTRACT

A study was undertaken to determine how the noise level due to free-flowing traffic is affected by the insertion of a traffic light. Field measurements were taken at eight different traffic light locations representing two configurations; that of two intersecting straight roads, and a tee junction. A reference level measured at a point where traffic noise was unaffected by the intersection was used in conjunction with the NRC Traffic Noise Prediction Model to assess the change in noise level in the region about the traffic light.

There are a fairly large number of mathematical models currently being used to predict the noise level produced by automobile and truck traffic. Most of these models are based on the assumption that the traffic is free flowing. This is a perfectly acceptable approach when considering freeway traffic, but it is generally not applicable to urban or suburban situations. In such environments vehicles are constantly accelerating and decelerating in response to traffic control signals. In this context, then, it is useful to consider the effect of stop signs and traffic lights on the noise level emitted by a line of otherwise free-flowing traffic.

The effect of a traffic light is not necessarily the same as that of a stop sign. A traffic light will cause some of the traffic to stop, but a stop sign forces all of the traffic to stop. As insufficient data have been gathered from sites with stop signs, this paper will address only the problem of traffic lights.

When selecting sites for this study, two basic requirements were set down: first, that the main road should be straight and fairly heavily travelled, and that the distance to any other interuption in the traffic flow be sufficiently far removed to permit a free-flow condition; second, that there should be no buildings or other reflecting surfaces in the vicinity of the intersection that could influence the measured levels. Eight intersections were selected for this initial study, including four different configurations as shown in Figure 1. Three sites were the intersections of two divided roadways, one was the intersection of two simple roads, three were tee intersections, of

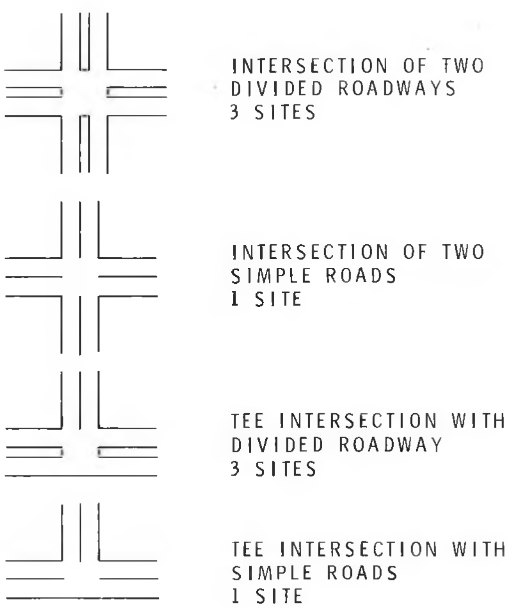


FIGURE 1
INTERSECTION CONFIGURATIONS

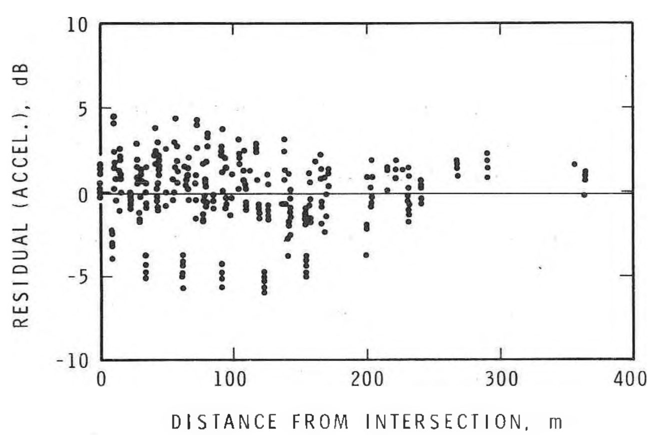


FIGURE 2
RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ON ACCELERATING SIDE OF ROAD

which the main road was a divided roadway, and one a tee intersection of simple roads. At all eight sites the main road was straight and level, although this was not always true of the second road. Fortunately the traffic on the second road was generally light, so that errors caused by the less than ideal conditions are expected to be small. At some of the sites not all of the second road was visible from all microphones. This tended to be self-compensating because the microphone with the smallest angle of view was also located farthest from the intersection, so that any error due to this factor is minimized.

Data were collected using 6 dB 301 Metrologgers manufactured by Metrosonics Inc. These data loggers have a 1/4-in. ceramic microphone equipped with a windscreen, and meet ANSI S1.4 1971 type II specifications. The A-weighted sound level is sampled four times per second; the equivalent sound level (Leq) is computed at the end of each minute and stored for subsequent readout. The data can be read out of each logger with the appropriate reader unit and the time history of the Leq printed out for 1-min intervals. At the end of each measurement period a calibration signal was included in the data set.

The microphones were positioned along the side of the main road of each intersection in a line stretching from the intersection to a point sufficiently distant for the sound level to be no longer influenced by the intersection. This distance varied from 200 to 300 m depending on the particular intersection. The microphones were stationed 1.5 m above the ground and usually about 2 m from the edge of the pavement.

Measurements were usually made along both sides of the road and occasionally along the central median; for each microphone configuration four to eight measurement runs were made, each lasting 15 min, during which time the traffic density and the percentage of heavy vehicles were recorded.

The first step in analysis is to subtract from each measured level the level that would have been present had the traffic light not been there. The simplest way to accomplish this is to consider only the difference in equivalent level between microphones for any single measurement period. Unfortunately this approach has two inherent limitations: no allowance is made for differences in the distance of microphones from the road or variations in topography along the road, nor is any correction made for traffic on the intersecting road. These difficulties were overcome by considering the residual, that is the difference between the measured level and a calculated level for each microphone rather than the differences between microphones. In this case the residual is the difference between the measured level and the level calculated using the NRC Traffic Noise Prediction model.[1] This was done by assuming that the traffic on both the main road and the intersecting road was free flowing. The residuals, as a function of distance from the intersection, are shown in Figures 2 to 4 for measurements made on the accelerating and decelerating sides of the roadway and along the median. The solid lines are a least squares fit to the data.

The scatter in the data can be reduced somewhat by assuming that the residual at the microphone most distant from the intersection is zero. This is not an unreasonable assumption; the prediction model is based upon an average of many measurements so that measurements at any one site would be expected to deviate from the model because of topographical variations, variations in pavement type, etc. This allows a more meaningful comparison of different intersections. Figures 5 to 7 show the same data as Figures 2 to 4, with this adjustment to remove variations that may be considered site specific. Again, the solid lines are the least square fit through the data.

Some trends are apparent. Figures 5 and 6 for the accelerating side and median show a clear trend towards higher levels closer to the intersection, with this trend more marked for the accelerating side. The trend on the decelerating side (Figure 7) appears to be towards lower levels closer to the intersection, except in the first 40 to 50 m where the levels are higher than for the free-flow situation. More will be said of this feature later.

Aside from the distance to the intersection there are three other obvious parameters that may affect the sound level. These are the speed of the traffic, the percentage of heavy vehicles, and the timing of the light cycle. The eight cases selected for this study do not have sufficient variation in traffic speed or light cycle timing to allow any meaningful statement to be made with regard to these parameters.

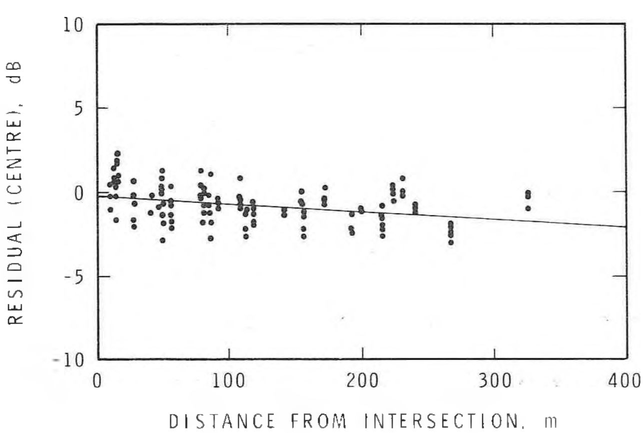


FIGURE 3

RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ALONG MEDIAN OF ROAD

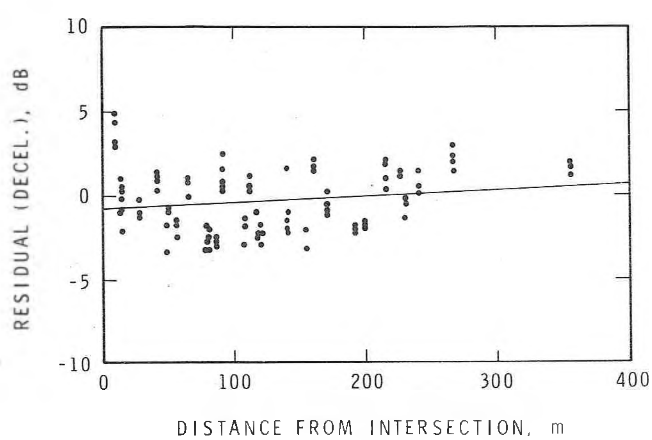


FIGURE 4

RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ON DECELERATING SIDE OF ROAD

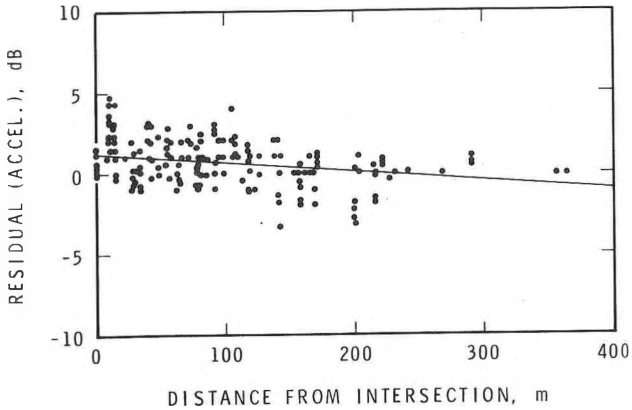


FIGURE 5

NORMALIZED RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ON ACCELERATING SIDE OF ROAD

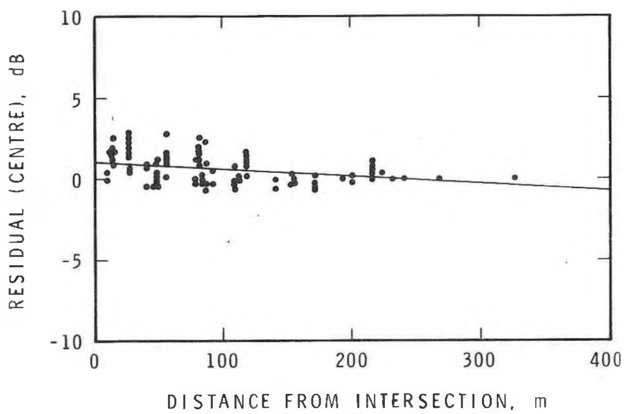


FIGURE 6

NORMALIZED RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ALONG MEDIAN OF ROAD

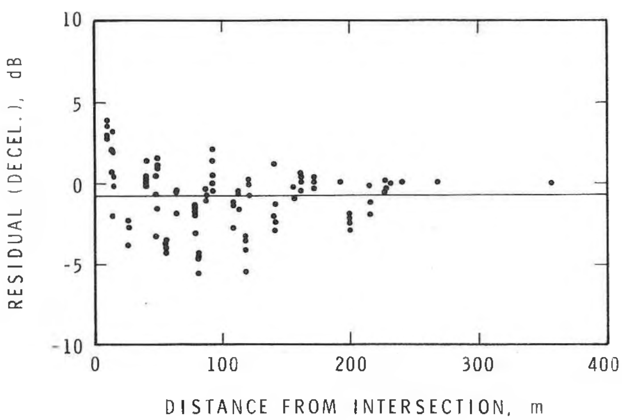


FIGURE 7

NORMALIZED RESIDUAL AS FUNCTION OF DISTANCE FROM INTERSECTION ON DECELERATING SIDE OF ROAD

Measurements were made over a wide range of the percentage of heavy vehicles, and the residuals are plotted against this variable in Figures 8 to 10. No clear dependence on percentage of heavy vehicles is apparent, suggesting that, at least for the sites studied, this is not a necessary parameter for a good first estimate of the effect of traffic lights on noise level.

A consideration of the regression lines in Figures 5 to 7 suggests that there is an increase in noise level as traffic accelerates away from a stop and a decrease as it decelerates to a stop. On this basis a simple correction to the noise level was made as shown in Figure 11. This is a profile of the excess noise level as a function of distance from the intersection for each lane. When this correction is included in the calculated level and the resultant residuals are plotted as a function of distance the results are as shown in Figures 12 to 14. It is apparent that, although not a perfect fit, the regression lines show that the profile used does have the right features. The worst deviations are found on the decelerating side. This is an artifact of the simple model used, which takes the zero of distance to be at the centre of the intersection, not at the stop line. In actual fact cars usually decelerate to the stop line and later accelerate through the intersection, shifting the profile centres from the centre of the intersection to the stop lines.

A model of this type was tested against the data and found to remove the apparent peak in the residual for distances less than 40 m on the decelerating side. The residual, however, still systematically deviated from zero for the decelerating side, and it is believed that further

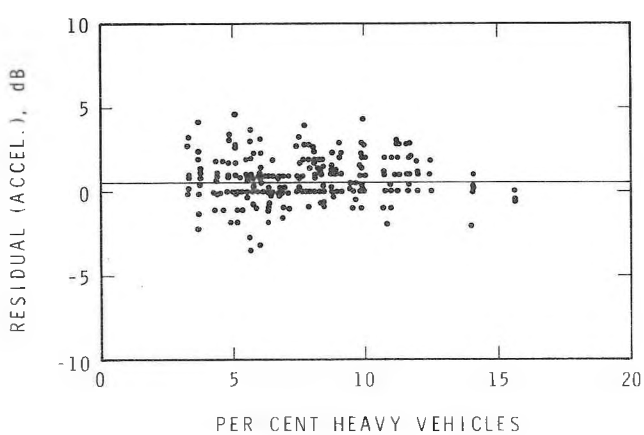


FIGURE 8

NORMALIZED RESIDUAL AS FUNCTION OF PER CENT HEAVY VEHICLES ON ACCELERATING SIDE OF ROAD

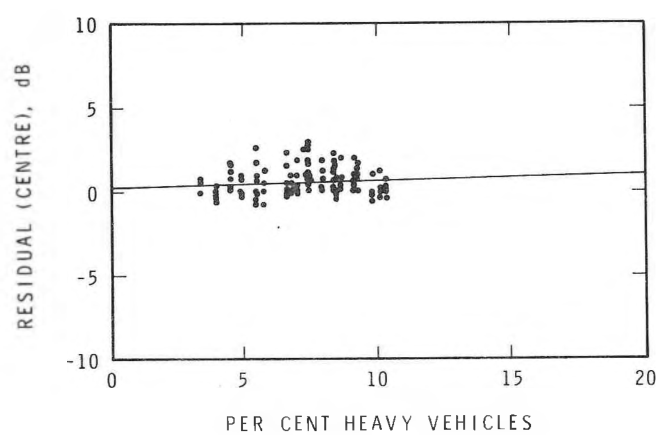


FIGURE 9

NORMALIZED RESIDUAL AS FUNCTION OF PER CENT HEAVY VEHICLES ALONG MEDIAN OF ROAD

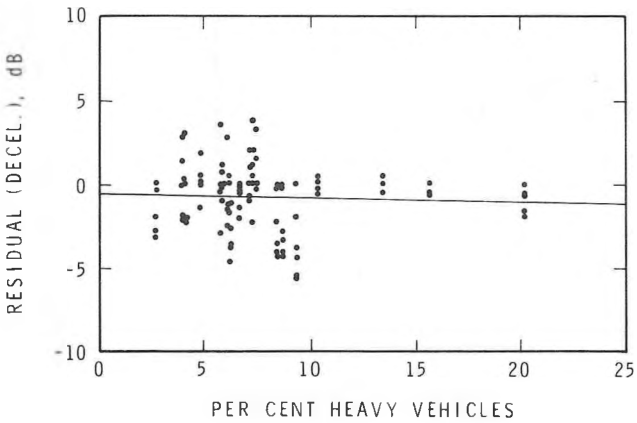


FIGURE 10

NORMALIZED RESIDUAL AS FUNCTION OF PER CENT HEAVY VEHICLES ON DECELERATING SIDE OF ROAD

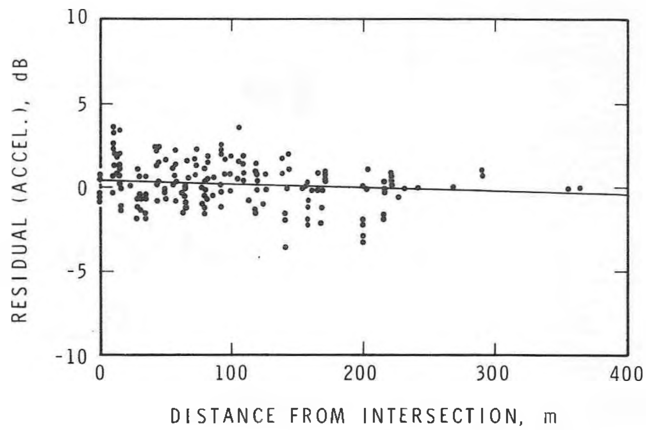


FIGURE 12

NORMALIZED RESIDUAL, AFTER CORRECTION, FROM INTERSECTION FOR ACCELERATING SIDE OF ROAD

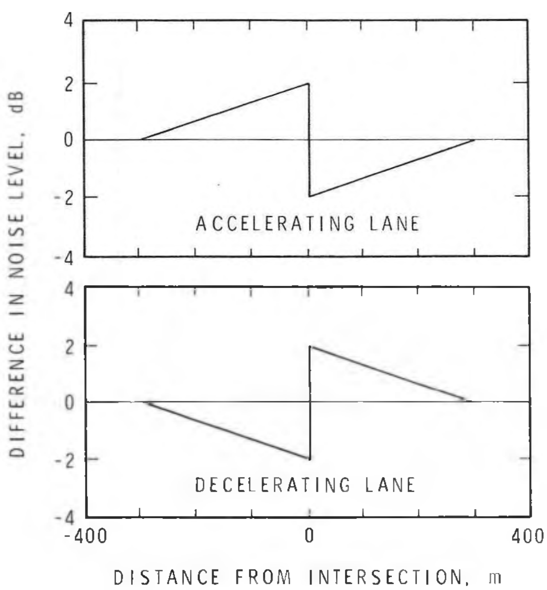


FIGURE 11

SUGGESTED EXCESS NOISE LEVEL PROFILE

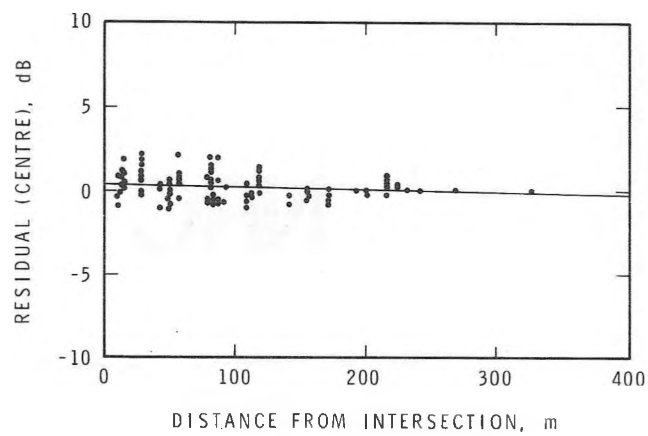


FIGURE 13

NORMALIZED RESIDUAL, AFTER CORRECTION, FROM INTERSECTION FOR MEDIAN OF ROAD

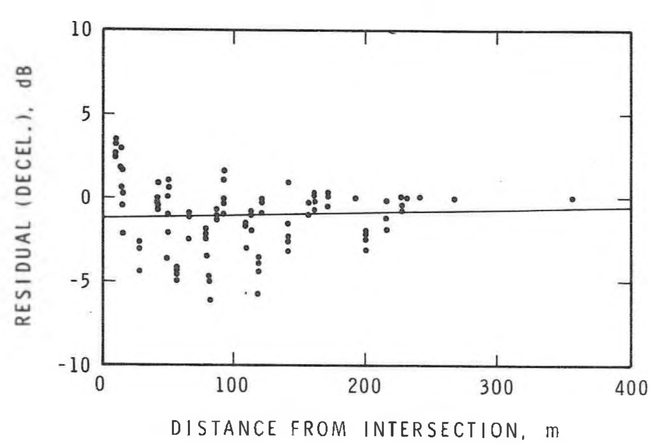


FIGURE 14

NORMALIZED RESIDUAL, AFTER CORRECTION, FROM INTERSECTION FOR DECELERATING SIDE OF ROAD refinements of the model should wait until a larger data base has been established.

It appears that there is a small but measurable increase in noise level in the vicinity of traffic lights and that this increase can probably be modelled in a simple manner.

Acknowledgement

The author wishes to thank J.D. Quirt for his invaluable advice and assistance. This paper is a contribution from the Division of Building Research, National Research Council of Canada and is published with the approval of the Director of the Division.

Reference

1. T.D. Northwood, J.D. Quirt and R.E. Halliwell, "Residential Planning with Respect to Road and Rail Noise," Noise Control Engineering, 13, 2 (1979).

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