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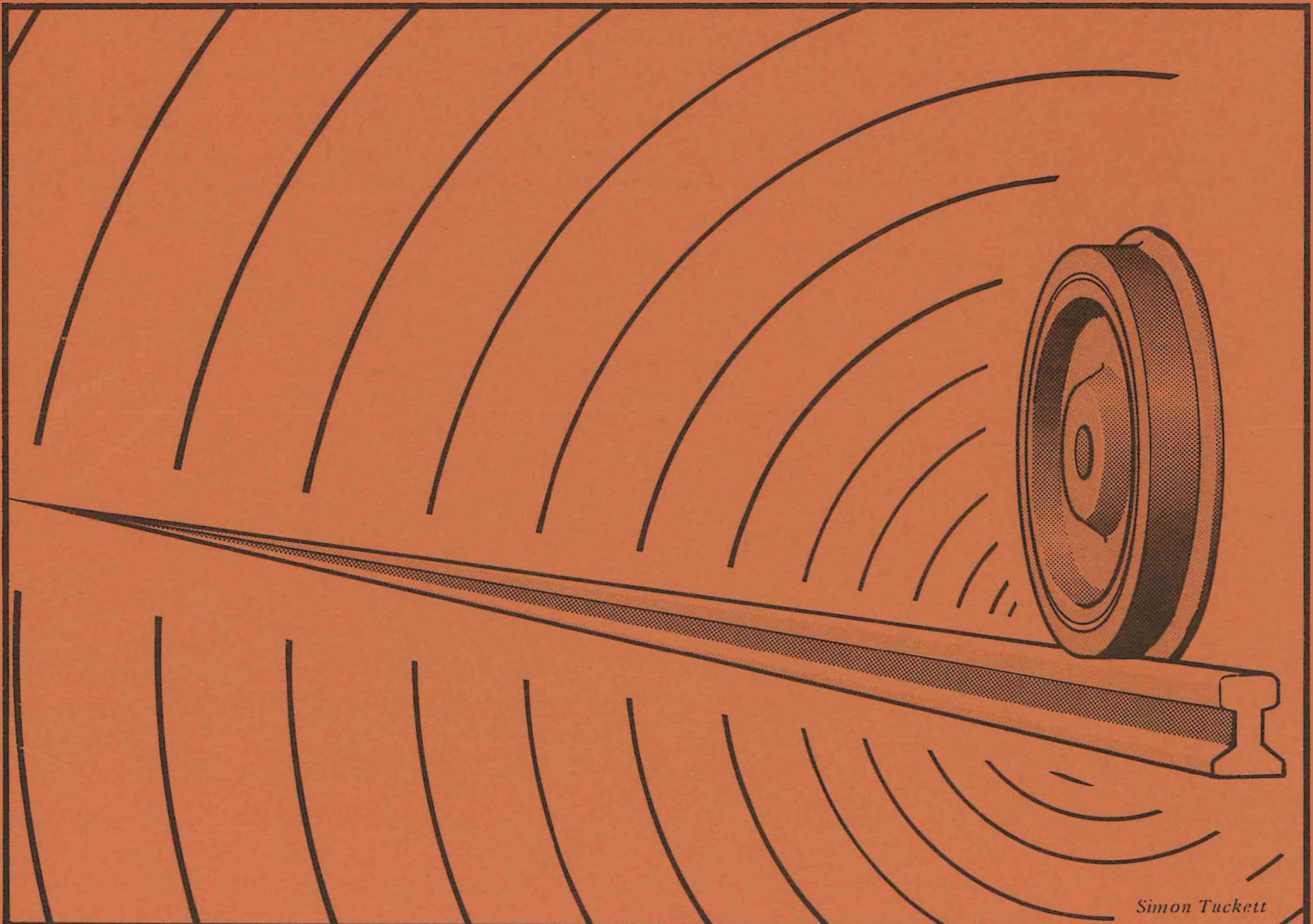
acoustics and noise control in canada

l'acoustique et la lutte antibruit au canada

Our cover illustrates the paper starting page 4



acoustics and noise control in canada

The Canadian Acoustical Association
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NEW RESEARCH CONTRACTS

To Hawker Siddeley Canada in Vancouver, $480,840 for the investigation of noise control techniques for wood chippers. Awarded by National Research Council.

To Memorial University of Newfoundland, Dept. of Physics (Dr. M. J. Clouter), $9,200 for examination of the acoustic properties of clathrate hydrates by brillouin spectroscopy. Awarded by Dept. of Energy, Mines and Resources.

To University of Saskatchewan, Dept. of Geological Sciences, (Dr. M. S. King), $8,430 for research into the acoustic properties of clathrate hydrates and hydrate-saturated porous rocks. Awarded by Dept. of Energy, Mines and Resources.

JOB WANTED

PHILIPPE DE HEERING is looking for a research and/or development position in the field of applied acoustics, preferably in Ontario. He is at present heading a research project concerned with the applications of parametric arrays to underwater communications. He has numerous publications on detection, classification, applied statistics, operations research and underwater sound propagation, and considerable experience of work at sea. The applicant is fluent in English, French, Russian, Italian and Dutch. Please contact him directly c/o SACLANTCEN, viale San Bartolomeo 400, I-19026, La Spezia, Italy, tel. (187) 503540.

EDITOR REQUIRED

"Acoustics & Noise Control in Canada" requires a Production Editor to assist the Editor in arranging and checking typing, and in laying out the journal attractively. Acoustical experience is less important than proven editorial, secretarial, drafting or artistic skills. Ready access to good typewriters, correction fluid and copying facilities is a must. No pay is offered, and the Production Editor must be prepared to work accurately, to deadlines, and within the small available budget. This is possibly an opportunity for aspiring production editors to gain experience and exhibit their work. Interested candidates should please contact the Editor at the address inside the front cover of each issue.

APPEL AUX ARTICLES EN FRANÇAIS

Notre journal est publié en français et anglais - mais il manque des nouvelles et articles en français. Auteurs francophones: Rappelez vous de notre journal quand vous envisagez publier. Nous aimerions entendre plus de vous.

CALL FOR PAPERS 2

The Annual Symposium of the Canadian Acoustical Association will be held in Windsor, Ontario on October 25-26, 1979. The theme this year is:

"THE AUTOMOBILE AND ITS ACOUSTICAL ENVIRONMENT"

Papers on all aspects of acoustics are invited. Abstracts, not more than 100 words in length, describing proposed papers should be submitted as soon as possible for consideration and acceptance by the convenor:

Dr. Z. Reif, P. Eng.
University of Windsor
Department of Mechanical Engineering
Windsor, Ontario
N9B 3P4
Tel: (519) 253-4232, ext. 550

Arrangements for group accommodation have been made at the Wandlyn Viscount Hotel, 1150 Ouellette Avenue, Windsor. Further details of the program and room rates will be mailed separately.

APPEL AUX ARTICLES 2

Le Symposium Annuel de l'Association Canadienne de l'Acoustique aura lieu à Windsor, Ontario, le 25-26 octobre, 1979. Le theme de cette année-ci est:

"L'AUTOMOBILE ET SON ENVIRONNEMENT ACOUSTIQUE"

Des articles dans tous les domaines de l'acoustique sont appelés. Afin d'être considérés et acceptés, des résumés de 100 mots au maximum, décrivant des articles à présenter, doivent être remis aussi tôt que possible au convocateur:

Dr. Z. Reif, Ing. P.
Université de Windsor
Département de Génie Mécanique
Windsor, Ontario
N9B 3P4
Tel: (519) 253-4232, poste 550

Des préparatifs pour des logements en groupe sont pris avec l'hôtel Wandlyn Viscount, 1150 avenue Ouellette, Windsor. Des détails supplémentaires sur le programme et les prix de chambres seront envoyés séparément.

MEETING ANNOUNCEMENTS

International Congress on Acoustics

The 10th annual ICA will be held in Sydney, Australia in July 1980, using the theme "Acoustics in the 80's". Various satellite symposia and ISO/IEC meetings are also scheduled in Western Australia and in New Zealand, dealing with deafness and audiology, architectural and underwater acoustics, and noise control engineering. For further information, please contact the Secretary, 10th ICA Executive Committee, The Science Centre, 35-43 Clarence Street, Sydney, NSW 2000, Australia

Society of Automotive Engineers

The 1980 SAE Congress and Exposition will be a special one to mark the Society's 75th Anniversary. The session on Vehicle Noise Regulation and Reduction will also be the subject of an SAE Special Publication to record progress in this field. The meeting will take place in Detroit in the week of February 25-29, 1980. Authors interested in contributing papers should please contact the co-organizers, D.N. May and M.M. Osman, at the address shown on the inside front cover of this issue.

AVIS DE REUNIONS

Groupement des Acousticiens de Langue Française (G.A.L.F.)

La Réunion Annuelle du G.A.L.F. (Groupe de la communication parlée), et leur 11èmes Journées d'Etude sur la Parole, seront organisées à Strasbourg (France), par l'Institut de Phonétique, du 28 au 30 mai 1980. Les thèmes généraux de ce meeting sont les suivants: (1) Perception de la parole, (2) Intelligibilité et qualité de la parole naturelle, de la parole codée et de la parole synthèse, (3) Variabilité inter et intra locuteurs (aux niveaux articulatoire et acoustique). Si vous êtes intéressé(e) à participer à cette réunion, veuillez vous adresser avant le 15 octobre 1979 à: Madame Péla Simon, Institut de Phonétique, 22 rue Descartes, 67084 - Strasbourg Cedex, France, Tel: (88) 61 39 39 - poste 291.
Note: French is the official language of the meeting, but the organizers tell us that English will also be used.

Congrès International en Acoustique

Le 10ème CIA aura lieu à Sydney, Australie en juillet 1980, sous le thème "L'Acoustique dans les années 80". En plus, des colloques satellites divers et des réunions de ISO/CEI seront organisés en Australie de l'Ouest et Nouvelle-Zélande, sur la surdité et l'audiologie, l'acoustique architecturale et sous-marine, et l'art de la lutte antibruit. Pour se renseigner, veuillez vous adresser au Secrétariat, 10th ICA Executive Committee, The Science Centre, 35-43 Clarence Street, Sydney, NSW 2000, Australia.

VIBRATION BEHAVIOUR OF THE MTC EXPERIMENTAL SUBWAY WHEEL

L. Strasberg, J. Tiessinga and K. Kono

Research and Development Division
Ontario Ministry of Transportation and Communications

ABSTRACT

The natural frequencies, mode shapes, and mechanical impedances of a resilient type subway wheel are presented. An impact method which uses Fourier techniques to analyse the vibrations of the wheel is described. Several natural frequencies and mode shapes not previously reported are presented.

INTRODUCTION

Rail transportation operating authorities consider railway noise a serious enough problem to commit large expenditures of capital and technology in an attempt to reduce it. The United States Department of Transportation, for example, has recently published a report which assesses the noise problems in several railed urban systems in the United States [1]. The South-East Pennsylvania Transit Authority (SEPTA) is testing ring damped wheels for the American Public Transit Association (APTA) [2]. In Canada, the Ontario Ministry of Transportation and Communications (MTC) has built several experimental streetcar and subway wheels with the aim of obtaining a better understanding of the wheel/rail noise problem [3].

It is believed that wheel/rail noise contributes a significant portion of the total noise emitted from electrically powered trains [4]. Because the noise associated with the wheel and rail comes about as a result of these components vibrating within the audible frequency range, it follows that reductions in these vibrations should abate the sound levels - provided the surface areas of the vibrating parts and their sound radiation efficiencies do not change in an adverse direction. In order to better understand the vibrating systems involved, the MTC is currently investigating the dynamic behaviour of several railway wheels.

This paper presents the results obtained when one MTC experimental wheel, the subway wheel shown in Fig. 1, was excited at frequencies within the audible frequency range. An impact technique was used. The dynamic parameters presented include the natural frequencies of the wheel, their associated mode shapes and some of the mechanical driving-point impedances and transfer impedances of the wheel.

EXPERIMENTAL PROCEDURE

The wheel was supported on rubber pads which were themselves mounted on a low frequency wooden platform of the type shown in Ref. 3. This support arrangement ensured that the wheel was in the free-free state. The wheel was struck by a specially made hammer to which a load cell was attached. An accelerometer was suitably positioned on the wheel. The signals from the load cell and from the accelerometer were routed to a dual-channel Fast Fourier Transform Analyser for processing. This instrument will rapidly break down both input signals into their Fourier components. In addition the machine is capable of performing several mathematical functions on these signals. The functions of interest for this paper include integration and differentiation. In addition, the instrument is capable of comparing signals (viz., by division) in both the time and frequency domains.

An ideal impulse may be considered as a dirac delta function, theoretically an infinite force acting for zero time. Fourier analysis on this signal will transform it into a continuous force signal throughout the entire frequency range. The signal obtained from the load cell attached to the hammer represents the impulse used to excite the MTC wheel. A typical signal is illustrated in Figs. 2 and 3 as channel B. In Fig. 2, it is seen that the impulse actually used had finite values for both the applied force and the time over which it acts. When Fourier analysis is used to transform this time varying signal into the frequency domain (Fig. 3), it is clear that the frequency content of the impact is also limited. This is not considered a serious limitation to the results because the upper frequency limit (15 kHz) is quite near to that of the human ear.

The vibration of the wheel resulting from the impact, is presented as channel A in Figs. 2 and 3. The first figure shows the vibration in the time domain, the second in the frequency domain. Because channel A in Fig.3, shows the magnitude of the respose at any given frequency, the peaks in the data represent those frequencies at which the wheel exhibits its maximum responses, ie. its natural frequencies.

The response of the wheel that results from excitation at various points is compared by using a quantity known as mechanical impedance. The mechanical driving-point impedance of the system is defined as the ratio of the force acting at a given point in a system to the resulting velocity at that point. It is a complex quantity having magnitude and phase, and is a function of the frequency of excitation. When the velocity is measured at a point other than the point of excitation, the term "transfer impedance" will be used. The input force for each investigation was measured via the load cell in the hammer (channel B) and the resulting velocity was obtained by integrating the output signal of the accelerometer on the wheel (channel A). The impedance was obtained as the ratio of channels B to A. Figure 4 shows a typical set of results obtained in this manner. Note that the natural frequencies of the wheel show up as steep "valleys" in this plot, ie. those frequencies at which a minimum of force gives a maximum amount of response. The results are presented in a slightly different form in Fig. 5 where the real and imaginary components are illustrated. The coherence between the signals is shown in Fig. 6.

RESULTS

Some of the results of these investigations are presented in Figs. 7 to 26.

The lateral point impedances of the MTC subway wheel are shown in Fig. 7. They were obtained by placing the accelerometer laterally on the front face of the rim, and striking the wheel laterally at a point as close as possible to the accelerometer. The natural frequencies obtained were essentially the same as those previously reported [3].

The mode shapes (Fig. 7) associated with the natural frequencies, were obtained with the aid of transfer impedances. The wheel was struck laterally on the rim at several different circumferential positions while the accelerometer remained at a reference location. Transfer impedances were thus obtained for the spatial locations shown in Figs. 8 to 14. By examining the impedances at the frequencies of interest, the resistance to motion of several points on the wheel were determined. Recalling that vibratory motion is assumed to be simple harmonic and by using the inverse of impedance, ie. mobility, the lateral motions of all points on the rim of the wheel were determined at each frequency of interest. Figures 15 and 16 show the plots obtained when the data associated with two of the natural frequencies were used in this manner. The remaining mode shapes were found by similiar methods.

The modes of vibration shown in Fig. 7 are due to the out-of-plane bending of the rim. Similar modes have been found by Stappenbeck [5] and by Strasberg [6]. These are the modes usually associated with squeal noise in lightly damped wheels [6]. In the subway wheel under investigation, rubber blocks were used to improve the damping ratios and hence lead to lower squeal noise levels. The damping ratios associated with these modes of vibration are presented elsewhere [3,6].

The radial impedances of the wheel tested are shown in Figs. 17 to 24. They were obtained in a manner similar to that described above, except that the tread of the wheel (ie., its running surface) was used for both mounting the accelerometer and as the location where the wheel was struck.

The mode shapes shown in Fig. 17 are associated with in-plane bending of the rim of the wheel. They, too, were obtained in a manner similar to that described above. As far as can be determined by a search of the relevant literature, many of these in-plane bending modes have not been previously reported. This may be a consequence of the method normally used to determine the mode shapes of a wheel, viz. to spread particles on the web of a wheel which is supported in the horizontal plane and then to shake the wheel at the frequency of interest. It is expected that a standard wheel would exhibit similar in-plane bending modes. However, for any given mode, the stiffer rim of the standard wheel should lead to a higher natural frequency than that associated with the thinner rim of the resilient wheel.

CONCLUSIONS

The radial and lateral impedances of an MTC subway type resilient wheel have been obtained. These mechanical impedances when used in conjunction with other relevant parameters, eg. surface areas and sound radiation efficiencies, may be used to predict the noise from this wheel.

Several vibrating modes, not previously reported, have been identified for a resilient railway wheel. These are shown to be associated with the in-plane bending of the rim of the wheel.

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6. Strasberg, L., Perfect, N., Elliott, G.L., "Some Static and Dynamic Properties of Railway Wheels", Publication 78-WA/RT-4, The American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, N.Y. 10017.

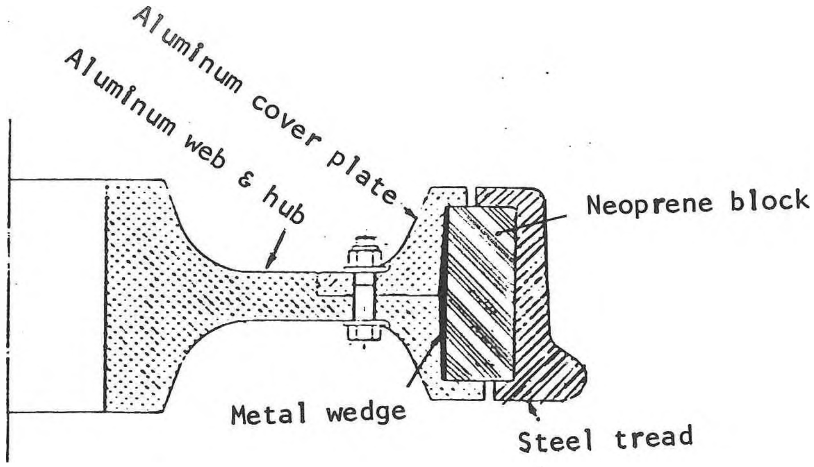


FIGURE 1: MTC Experimental Subway Wheel

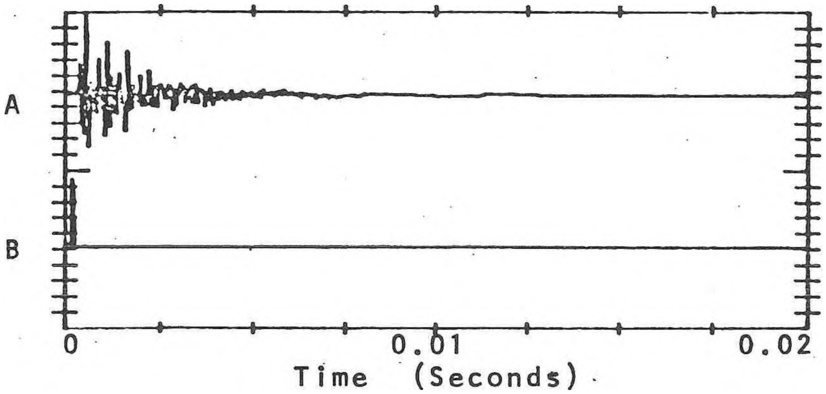


FIGURE 2: Time Response of Wheel (A) due to Hammer Blow (B)

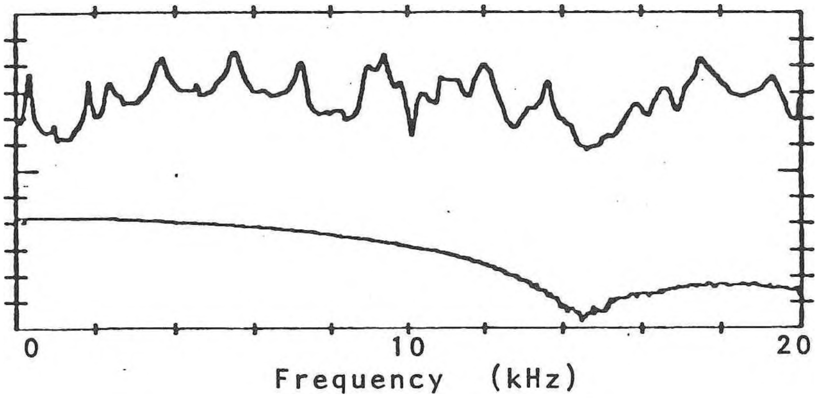


FIGURE 3: Frequency Response of Wheel (A) due to Hammer Blow (B)

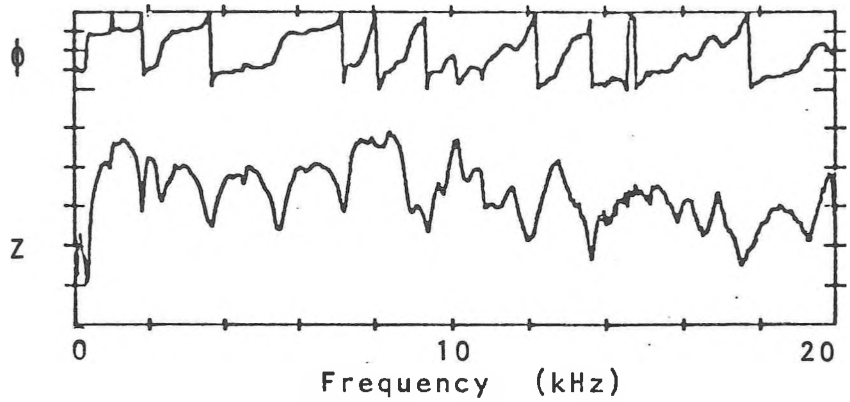


FIGURE 4: Impedance of Wheel (Typical Results)

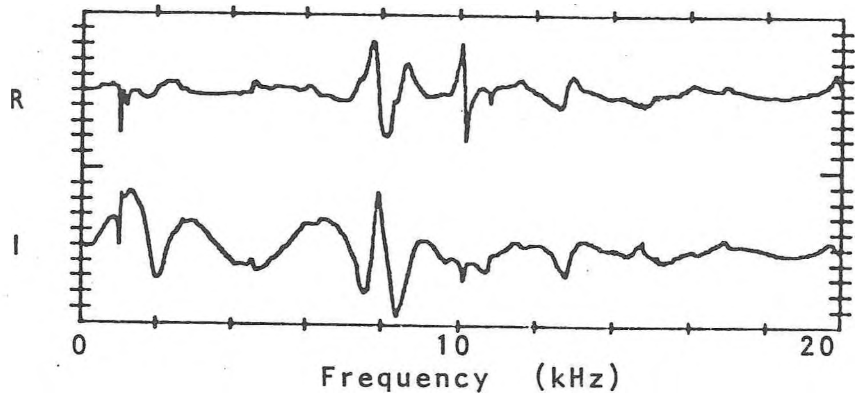


FIGURE 5: Impedance of Wheel (Typical Results)

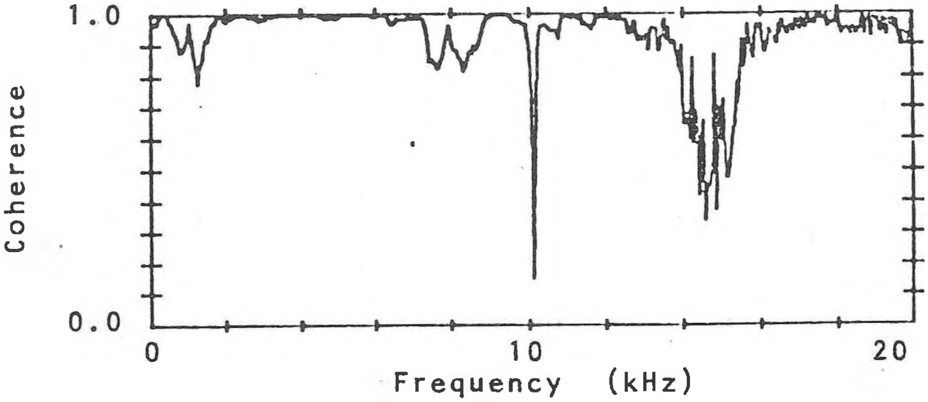
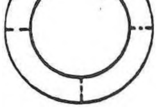
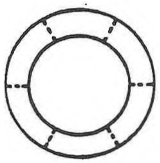
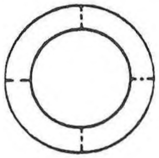


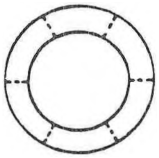
FIGURE 6: Coherences (Typical Results)

Note: Number of Nodal Circles not determined for these modes.


a
350 Hz


b
1000 Hz


c
2350 Hz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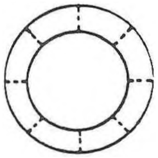
2850 Hz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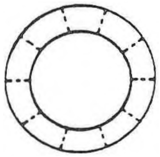
3650 Hz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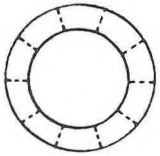
4550 Hz


g
4750 Hz

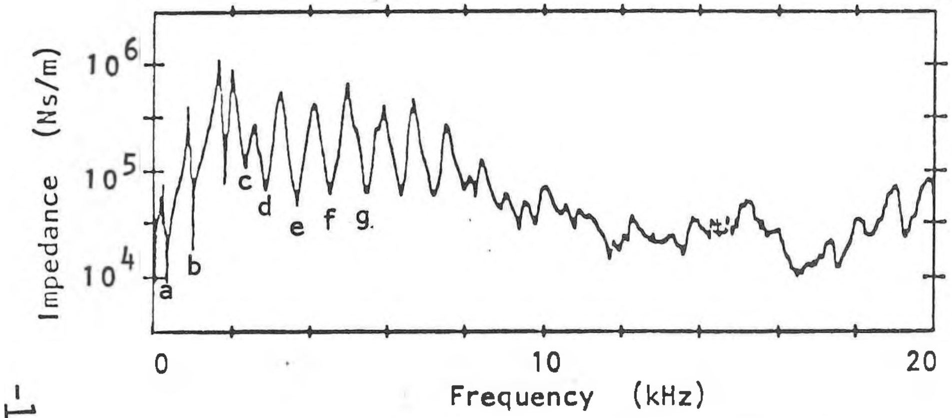


FIGURE 7: Lateral Point Impedance taken at 0°

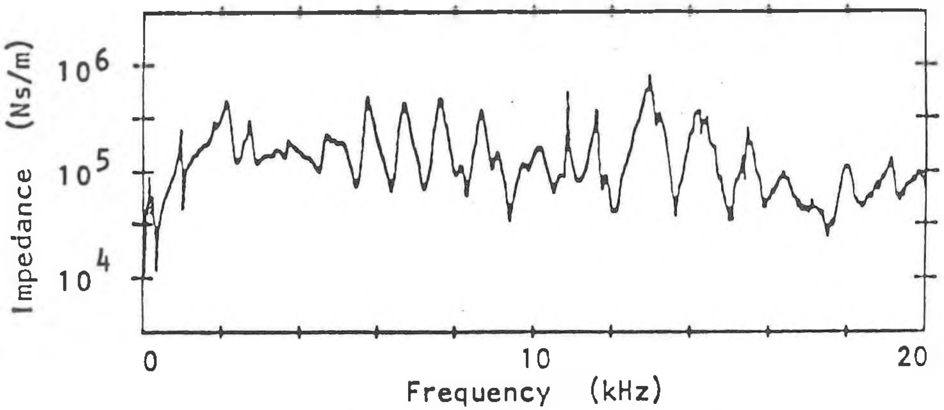


FIGURE 8: Lateral Transfer Impedance taken at 22½°

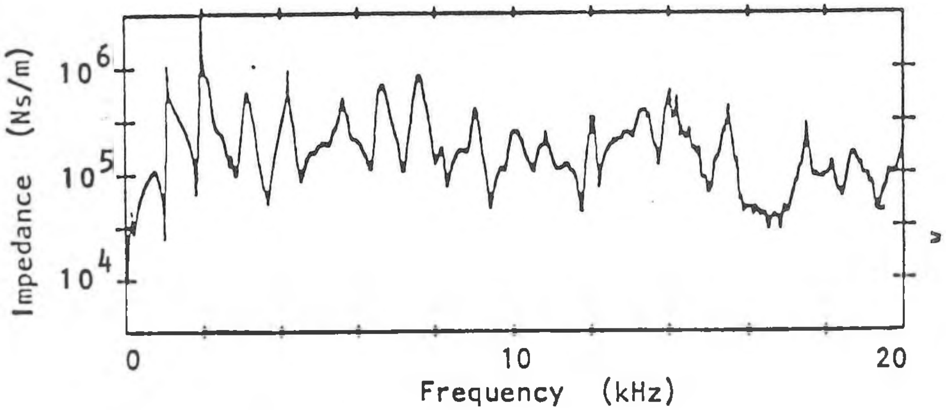


FIGURE 9: Lateral Transfer Impedance taken at 45°

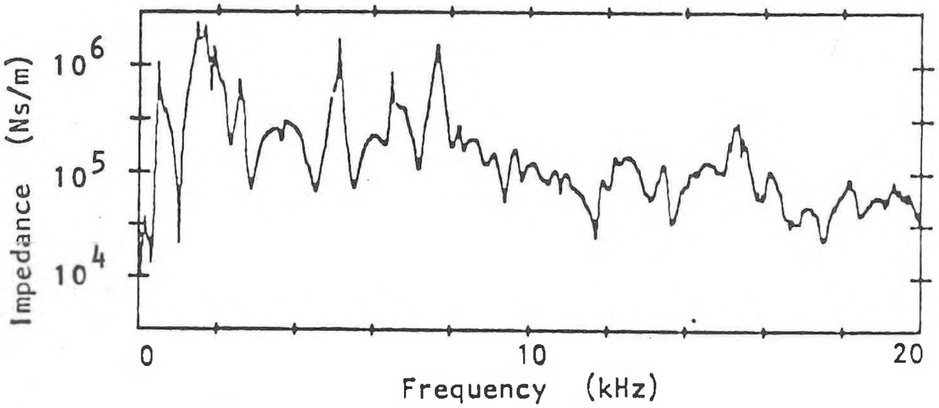


FIGURE 10: Lateral Transfer Impedance taken at 67½°

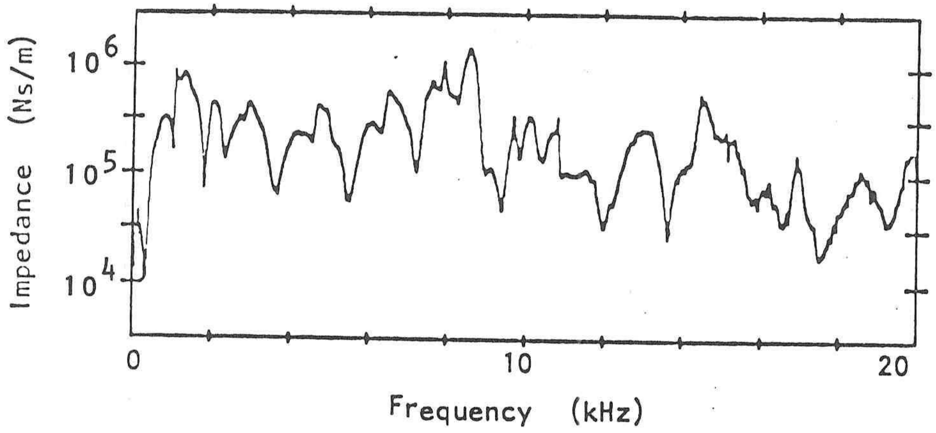


FIGURE 11: Lateral Transfer Impedance taken at 90°

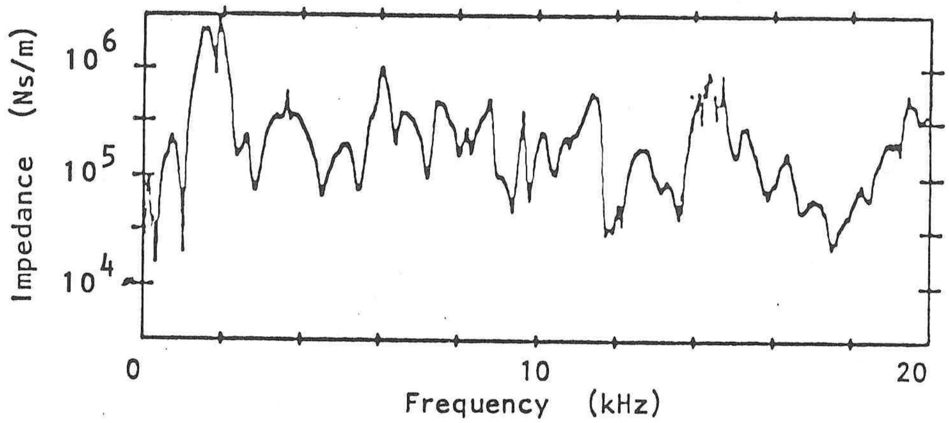


FIGURE 12: Lateral Transfer Impedance taken at 112½°

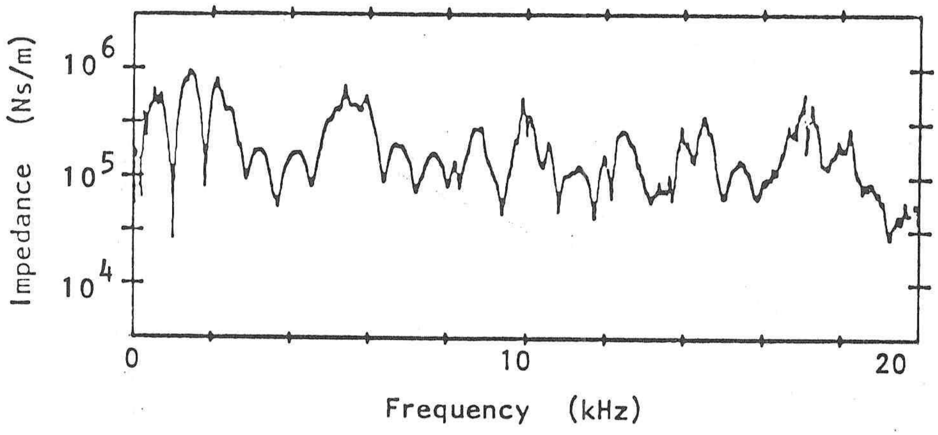


FIGURE 13: Lateral Transfer Impedance taken at 135°

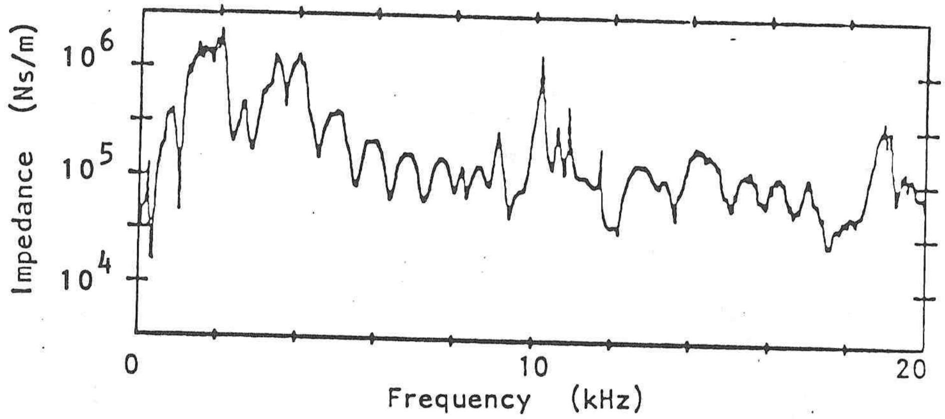


FIGURE 14: Lateral Transfer Impedance taken at 157½°

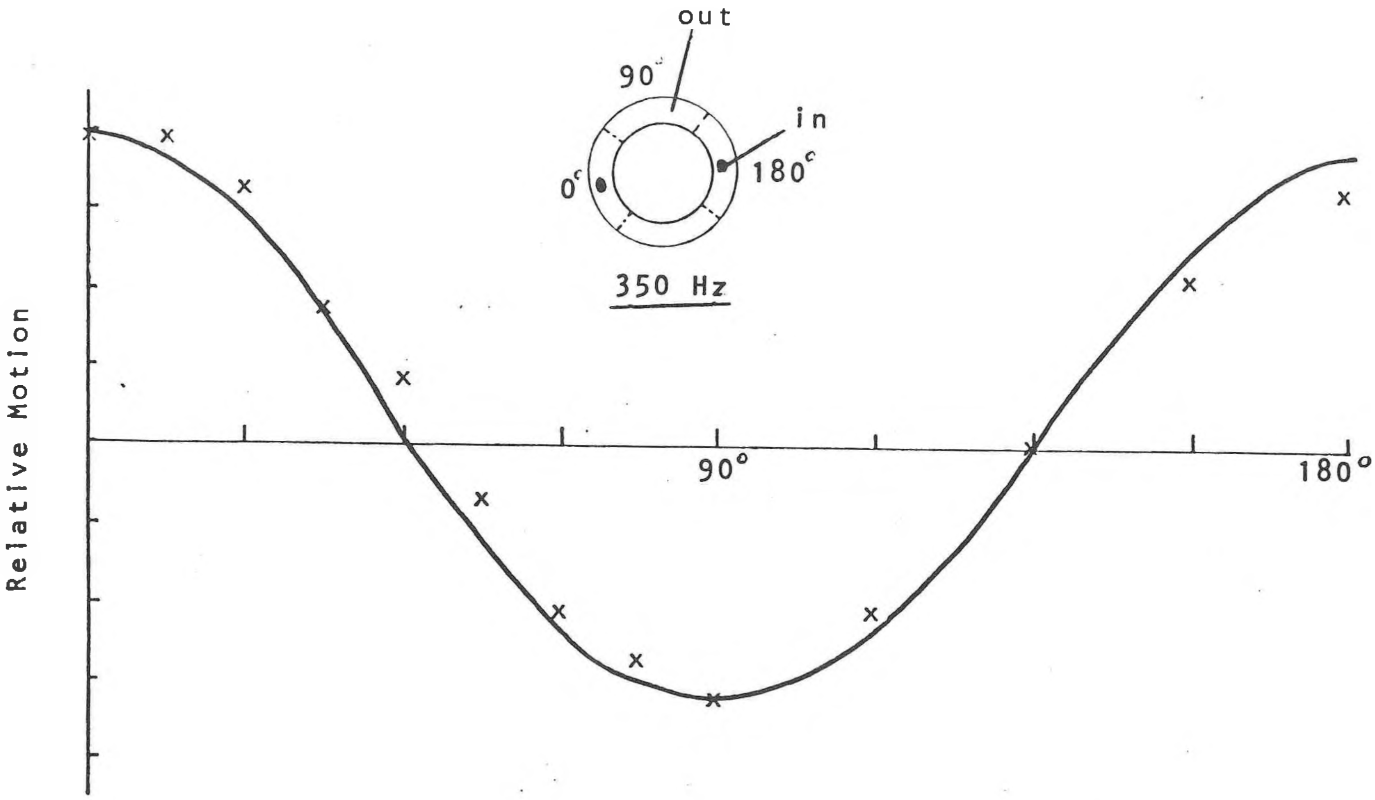


FIGURE 15: Relative Motion of Rim in Lateral Direction

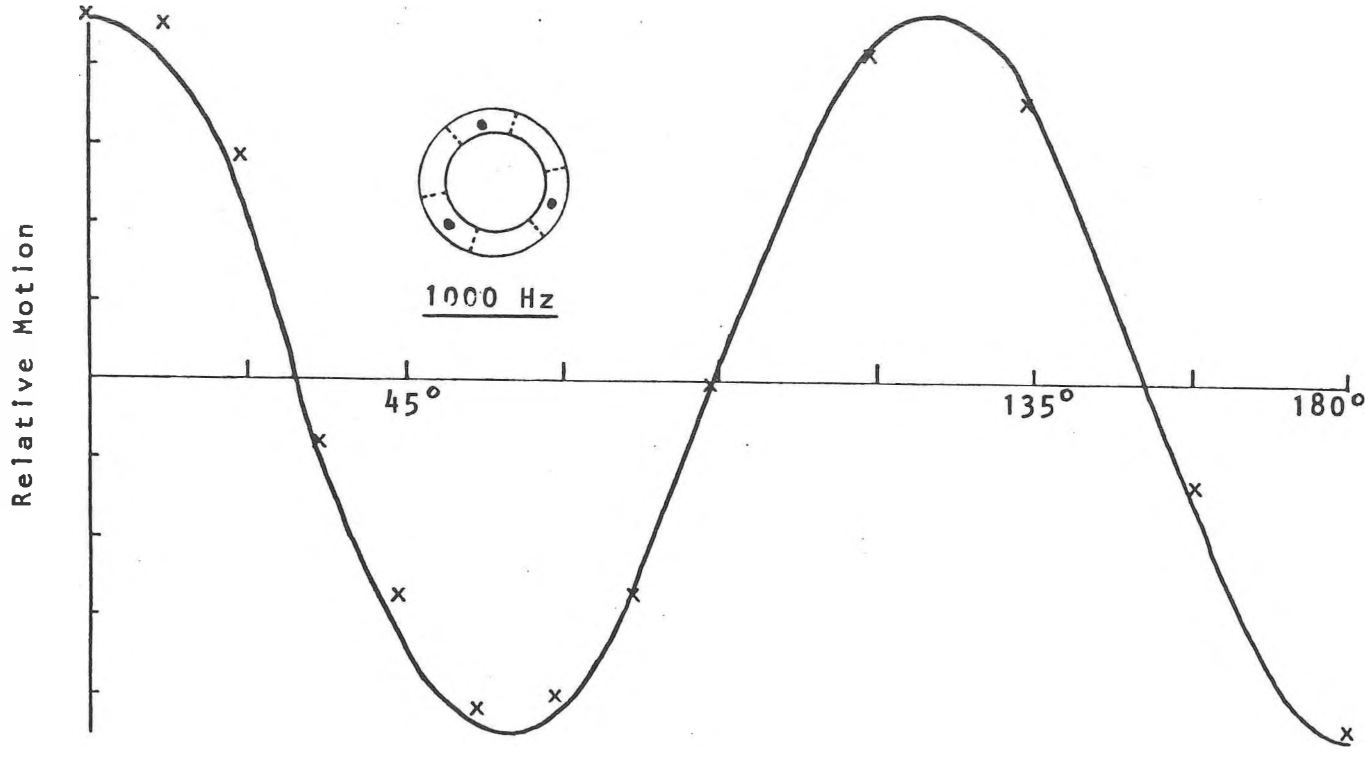
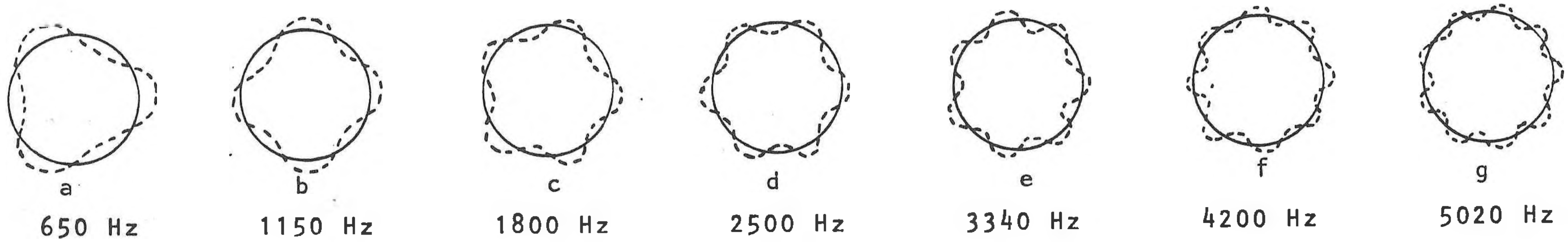


FIGURE 16: Relative Motion of Rim in Lateral Direction



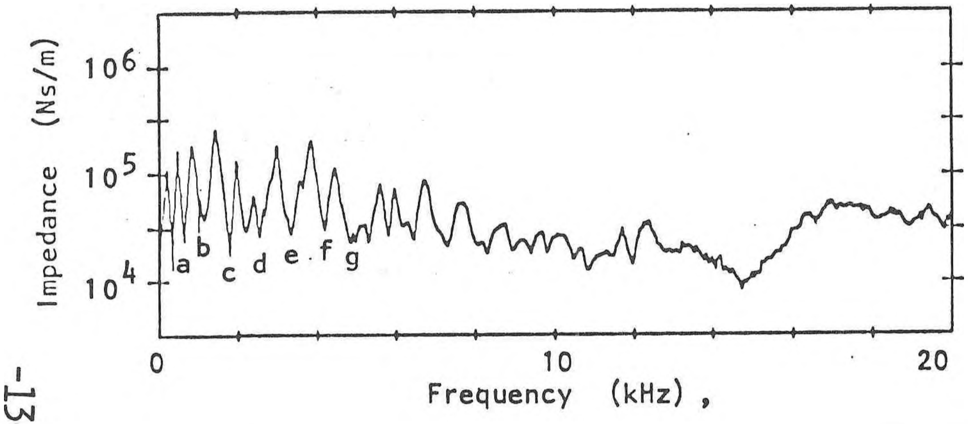


FIGURE 17: Radial Point Impedance taken at 0°

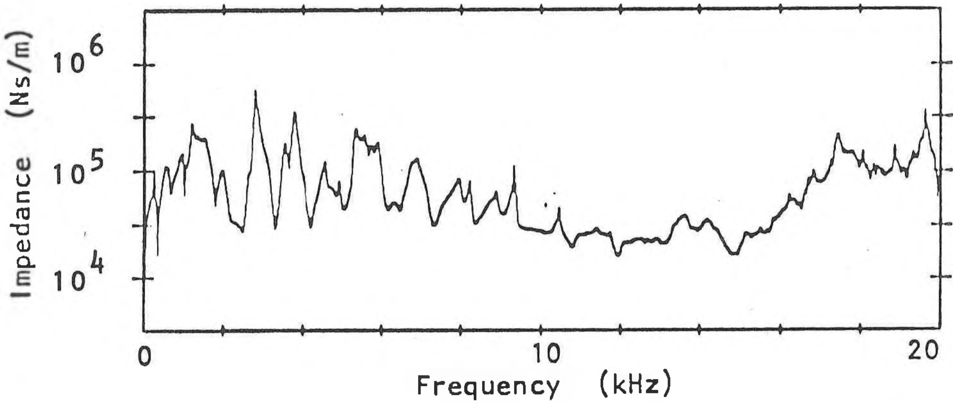


FIGURE 18: Radial Transfer Impedance taken at 22½°

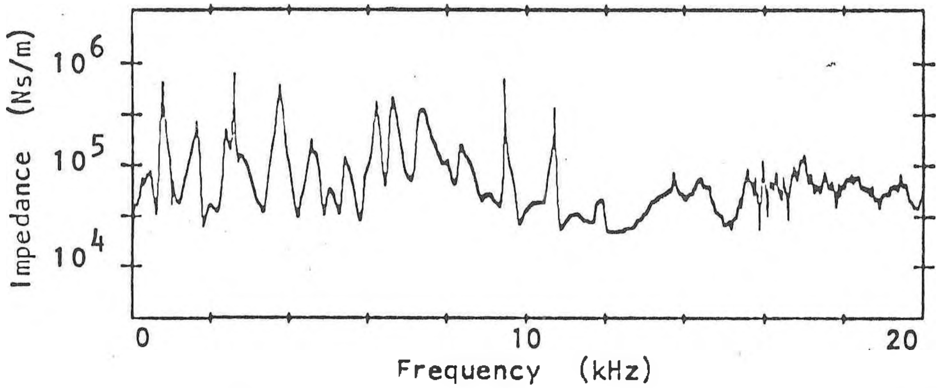


FIGURE 19: Radial Transfer Impedance taken at 45°

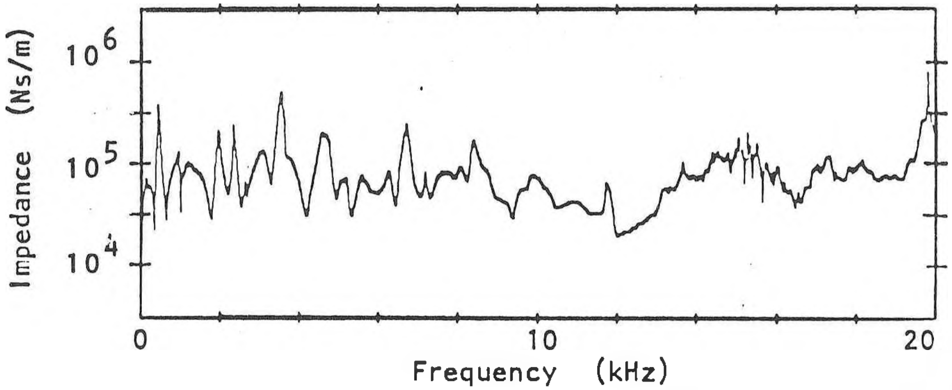


FIGURE 20: Radial Transfer Impedance taken at 67½°

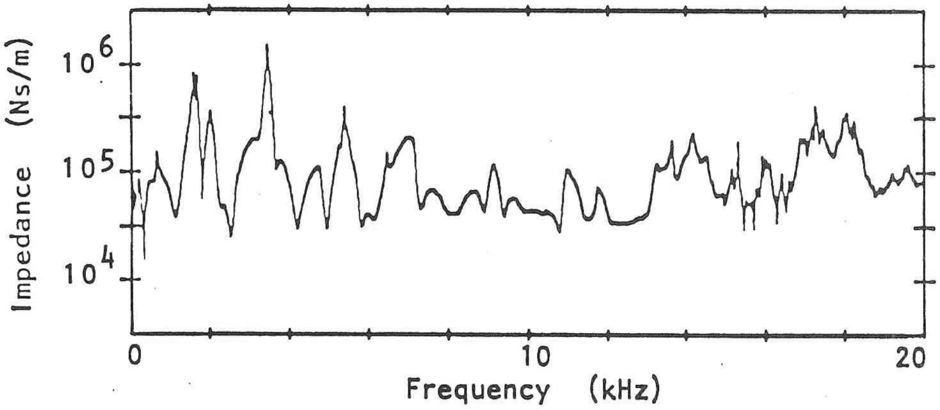


FIGURE 21: Radial Transfer Impedance taken at 90°

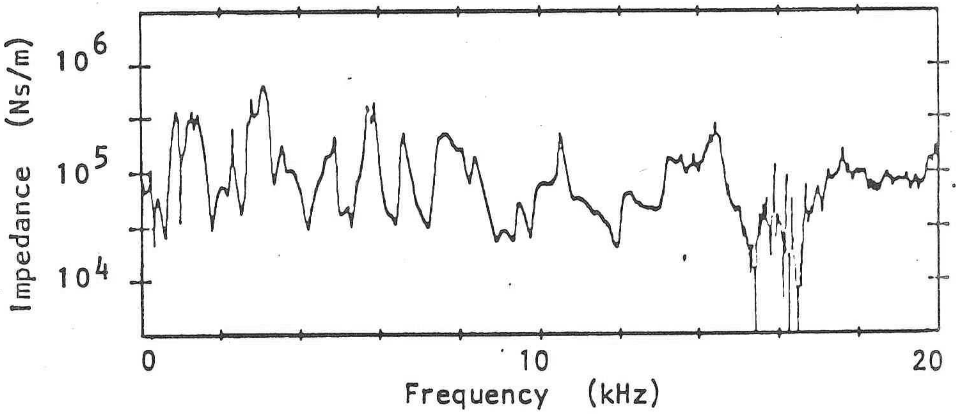


FIGURE 22: Radial Transfer Impedance taken at 112½°

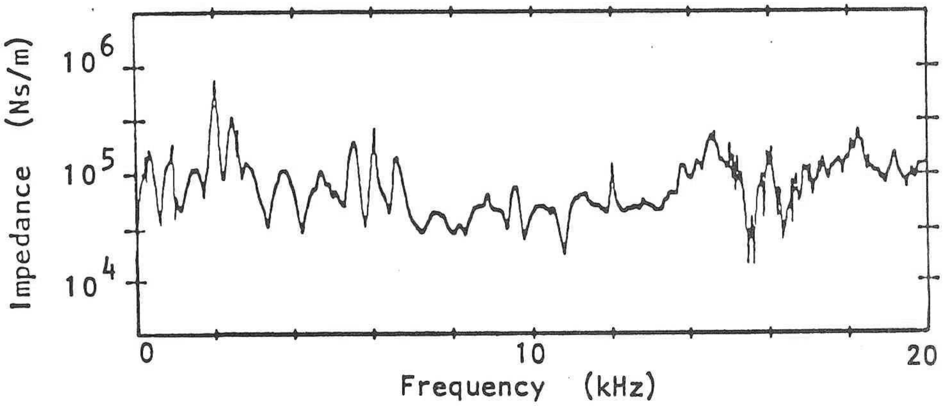


FIGURE 23: Radial Transfer Impedance taken at 135°

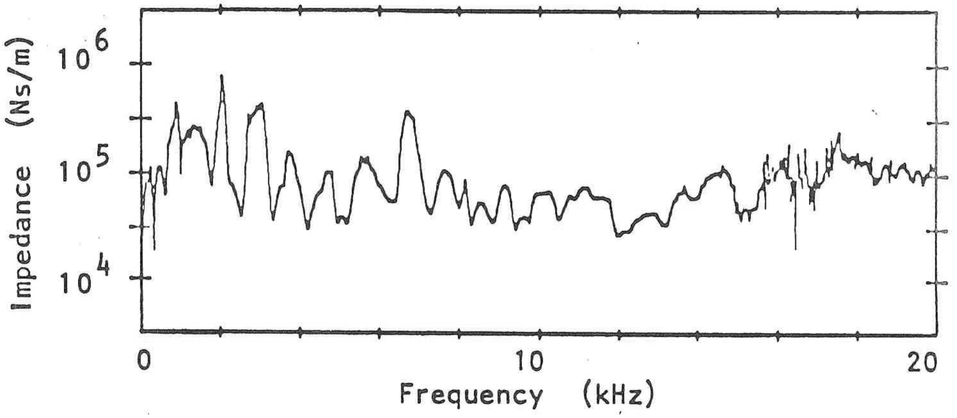


FIGURE 24: Radial Transfer Impedance taken at 157½°

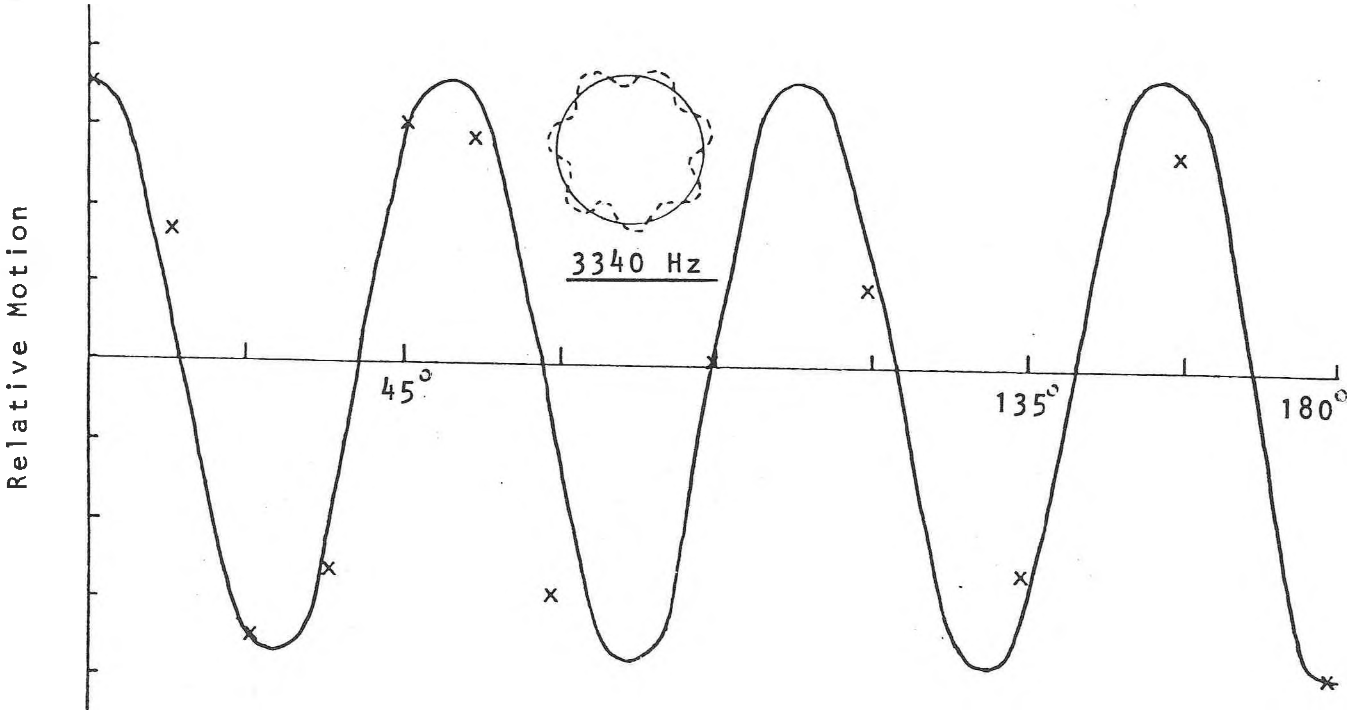


FIGURE 25: Relative Motion of Rim in Radial Direction

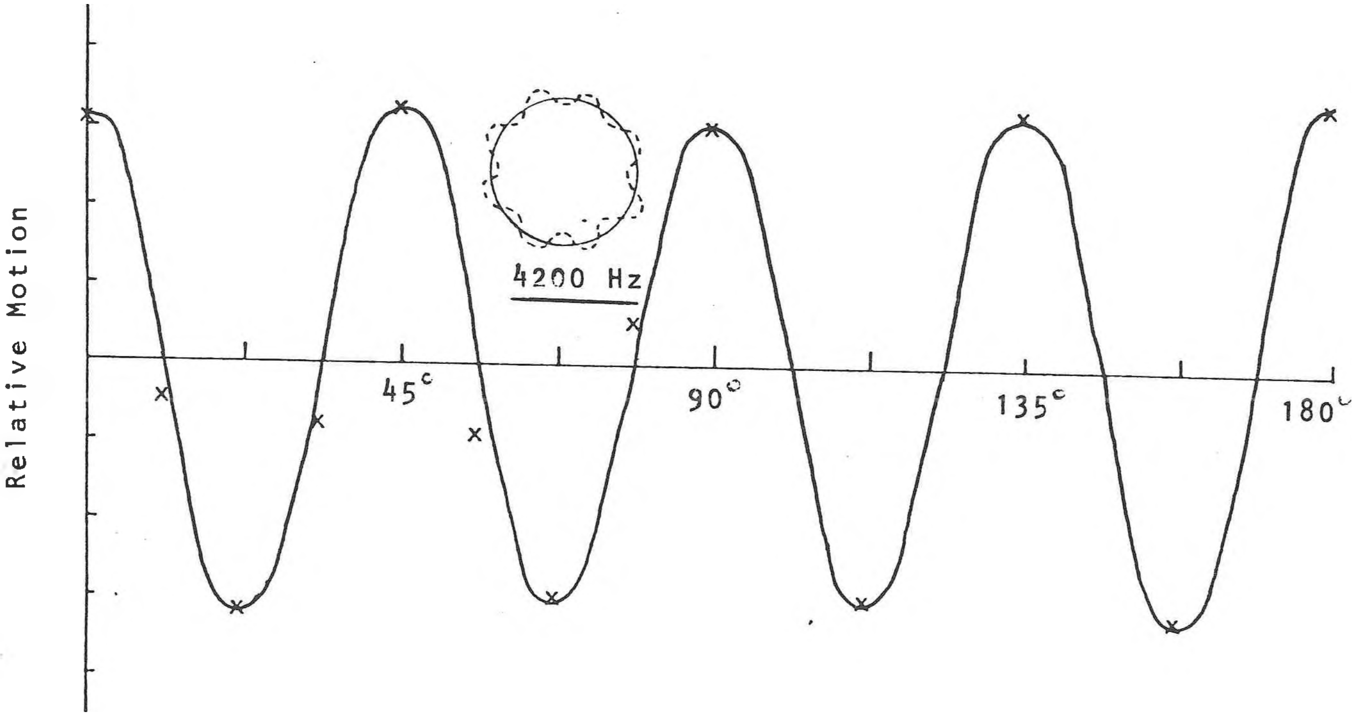


FIGURE 26: Relative Motion of Rim in Radial Direction

AN ENVIRONMENTAL STIMULUS FOR SUDDEN DEATH IN INFANCY?

Philip Dickinson

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Toronto, Salt Lake City, London

ABSTRACT

This paper contains a review of the environmental conditions that may be associated with Sudden Infant Death Syndrome (SIDS), and notes a probable association in Utah between SIDS and atmospheric temperature inversions accompanied by a gentle breeze. These conditions also enhance the strength of low frequency sound in rooms; moreover it is only in certain-size rooms and moving automobiles (another low frequency sound environment) that SIDS has been observed. The author argues that such sound could be one of the links in SIDS, perhaps through direct transmission into the skull via an infant's not-yet-closed fontanelle.

Sudden Infant Death Syndrome (SIDS) - the sudden death of any infant or young child, which is unexpected from its medical history, and in which a thorough post-mortem examination fails to demonstrate an adequate cause for death [1] - is the most common cause of post-neonatal mortality and accounts for about 1/3 of all infant deaths between the ages of 1 week and 1 year, or about 0.3% of live births [2]. It seems to be a common occurrence throughout history, the many accounts written suggesting that its frequency today may be no greater than it was in the past.

Some of the earliest SIDS investigation was by Dr. Charles Templeman [3] who, as a result of his investigation into infant death in the town of Dundee in Scotland, considered local crib deaths had been caused by suffocation. The theory persisted until the 1950's when pathologist Francis Camps, and virologist Sir Samuel Bedson, finally proved this was not the case. Following Templeman's theory, there was a host of other theories ranging from allergies to inhalation of toxic fumes, and from parental smoking to the after-effects of the birth control pill - besides those possible medical causes put out by responsible scientific researchers, a comprehensive listing for the latter being given in Reference 4.

After many years of research, an organic cause still eludes us. But research has tended to concentrate on the organic side rather than on an environmental cause or stimulus that may be of equal importance. This is not saying that the environment has been totally neglected, only that less emphasis has been placed on its possible involvement than on other causes. In terms of the physical environment, certain combinations of temperature, pressure and wind velocity [5,6] have been postulated to be significant. In terms of epidemiology, there is much ongoing work perhaps stimulated by the pioneering work of pathologist Professor John Emery of the University of Sheffield. His environmental investigations [7] concentrate on 8 main factors; mother's age, mother's blood group, the length of labour, the state of the amniotic fluid in the womb, the presence of any urinary infection, the weight and gestation time, the baby's food, and the number of previous pregnancies of the mother. The State of Utah is carrying out such an investigation under the direction of the Medical Examiner, and including many more parameters with some limited data on the physical environment as well.

The western countries, with their great concern for health and welfare, keep detailed statistics, which in the context of SIDS are very interesting: The death rate attributed to SIDS is reasonably constant at about 0.3% of live births, except in the Netherlands and Scandinavia, where it is under 0.1% of live births [8], and in Finland, where it would appear to be almost nonexistent. (Admittedly, these differences could be due to differences in reporting.) Strangely, the latter country has by far the greatest occurrence of heart failure anywhere [9] which may, or may not, be relevant. Scandinavian communities in the United Kingdom and in the United States do not seem to be less prone to SIDS than the indigenous population. This too suggests that environmental influences may be of great importance in SIDS.

In cooperation with the Utah State Department of Health Council on Sudden Infant Death Syndrome, the local chapter of the SIDS Foundation, and the Office of the Medical Examiner, some initial investigation of SIDS occurrence has been undertaken over a two year period.

In the State of Utah, by law [10] all unexpected infant deaths must be referred to the Medical Examiner. There were 36 SIDS occurrences in 1975, 48 in 1976 and 48 in 1977. All have been documented in detail by the Medical Examiner. Examination of these show a pattern that suggests a strong environmental component in the syndrome.

1) The very thorough autopsies always undertaken found no apparent reason for any of the deaths. For those occurring in an automobile, the presence of carbon monoxide or other exhaust gas was an obvious choice for investigation. But no suggestion of any such cause was found in child or automobile.

2) Examination of the "Emery Parameters" together with such items as: the position and orientation of the child in the crib, bed or seat, the clothing worn and its composition, the food and feeding history, past medical history, the mothers'

feeding history, mothers' immediate past medical history, drugs taken by the mother (this has been reported in detail elsewhere), recent air pollution, ventilation, calidity, genetics, etc., differed from case to case such that no connections were evident between any of these parameters and SIDS.

3) But in Utah, the occurrences are not spread randomly throughout the inhabited areas of the state, nor do they follow the lines of greatest population density. Although the majority of cases do occur in Utah's three largest cities, most cities and towns remain clear. Just over 91% of occurrences are within a narrow band less than 3 miles wide broken into three areas with a combined length of less than 45 miles. This band runs north-south down the centre of a valley bordered on the east by the Wasatch Mountains, and on the west by the Oquirrh Mountains and the Great Salt Lake.

4) The bounded area is prone to temperature inversions, the visual pollution of the valley making the demarcation very obvious in these conditions. With the cases examined and correlated with the weather conditions of the time - comprehensive data supplied by the Utah Department of Meteorology and the weather services of KUTV (Salt Lake City) with extra details from the National Weather Service - every case, except those in automobiles, occurred in conditions of a strong temperature inversion and a very gentle breeze.

5) Within this band, there is a proliferation of cases in two distinct areas of Salt Lake City - not the centres of dense population.

6) There is a fairly large incidence of multiple occurrence. In one 12 hour period, Salt Lake City had 4 cases of Sudden Infant Death (and a number of suicides). The occurrence of suicides is being investigated by the Medical Examiner's Office to see if there is any correlation with the times of SIDS occurrences. Data on this is not yet at hand. But this is of greatest interest because in some parts of the world the occurrence of some natural climatic phenomena results in a spate of irrational behaviour with a very significant increase in suicides. For example, it is understood that, in West Germany, many works close down when the Foehn Wind blows because of the severe effect of the apparently related irrational human behaviour on production.

7) Of all these cases of Sudden Infant Death in Utah, all but 3 occurred in the family residence, the exceptions taking place in a nursery room of a sports pavilion in the city, and in automobiles. Although Utah has extensive recreational facilities, and there is a very large family involvement in the outdoors, no occurrence of SIDS - in 8 years of documenting - has been found in any recreational home, i.e. in any travel trailer or small caravan, tent, motorhome, small houseboat, or cabin cruiser, and none from any Indian Community still inhabiting primitive dwellings such as hogans. The same result appears from inquiries made in

other countries and states. In view of the fact that the average healthy western infant spends a significant proportion of its time in an environment other than a house or car, if SIDS is a disease unrelated to the physical environment, it is reasonable to expect some deaths elsewhere.

8) Extensive inquiries among bus companies, airlines, railway companies and shipping lines failed to find any SIDS occurrence. Help was given in these inquiries by the Greyhound Bus Company, Continental Trailways, Western Airlines, Amtrak and the Cunard Shipping Company. The death of a child is not uncommon in travel, but no circumstances it was felt suggested the occurrence of the Syndrome.

9) Preliminary investigations carried out by the local public health nurses show that in all the cases in residences (during the last three years in Utah) the room was of medium to large size. No case occurred in a room of small dimensions - less that about 800 cu. ft.

10) The occurrences seem quite independent of the socioeconomic status of the family, but not necessarily independent of the lifestyle of the family. Whether the mother is a home-maker or not may be a factor but there is not enough data yet in hand to make any preliminary conclusion on this.

11) In the child's sleeping quarters, windows and doors generally were closed with only a small electric night-light in operation, if any light at all. Inevitably there are reports of badly fitting windows and some draughts - which may, or may not, be significant.

12) Of those parents who were willing to talk to the nurse about the child's death, all reported their child did seem unduly "fussy" in its sleep and cried during the late evening and/or night; for some of the children this was unusual. (This of course increases the parent's feelings of guilt making an investigation much more difficult.)

13) Lengthy discussions have been had with the curators and the pathologists of some of Western America's largest and famous zoological gardens. These included San Diego, Denver and Hogle zoological gardens. The discussions also included several veterinary surgeons in the State of Utah. These discussions revealed that there appears to be no analogy to SIDS in animals. The pathologist at the San Diego Zoo felt that SIDS in animals ought to be a real possibility and that his extensive records over the past 12 years should be examined in detail before a definite statement of "SIDS does not occur in animals other than man" were made. There were no recent (last 3 years) cases that fell within the category and certainly none amongst the primates. But just because SIDS was not apparent in this period, he felt (quite rightly) it should not be ruled out. Other zoos - Hogle being one - had no cases of infant animal deaths which their authorities felt might not have a straightforward medical cause.

The question may be asked, "If Sudden Infant Death Syndrome is a 'disease', why is it so selective that it strikes only in certain physical situations?" The results of these investigations do not support a 'disease' theory alone, but point to an environmental parameter as a prime contributor towards the death. By no means does this rule out a disease being necessary. It merely suggests it is not a disease alone. The author is led to believe that a chain of events and circumstances leads to the final event of death and that an initial stimulus may be a parameter of the physical environment.

In our atmosphere there are a large number of physical parameters. But the range is reduced significantly when one isolates those parameters that may occur not only in a house, but also in a moving automobile, and not elsewhere. Of those physical parameters that we understand - and we must face the fact that there may be others of which we are totally unaware - some obviously call for examination: parameters such as static electricity, noise and vibration.

Noise is so far the only one of these to be investigated in Utah - because of the difficulties in forming a measurement technique for the other two - but some of the findings suggest there is a strong case for suspecting it to be very relevant. One of the few things in common with a medium sized room (as distinct from a small room) and a moving automobile is the natural low frequency resonance possible. In a car the low frequency sounds, it has been suggested [11], can be strong enough to affect the reaction time of the driver, but in a house one would not expect such intensities unless there is a source of such sound, and some enhancement (amplification) mechanism to make the sound effectual at a particular point and time. There is such a source of natural sound in the atmosphere that does disturb a large number of people [12] occurring, for reasons unknown, during peroods when there is a temperature inversion and gentle breeze, and rarely at other times. But the sound levels are extremely low (30 - 40 dB in the 31.5 Hz octave band) and the majority of people cannot hear the sound at all.

In a room, some enhancement is possible if the design and construction of the room, together with the temperature of the internal air, match the characteristics of the incoming sound. While high pitch sounds behave like light rays, being constantly reflected and re-reflected by the walls and ceiling of a room until finally they die away, low frequency sounds behave in a rather different way [13]. When the wavelength of sound is the same as one of the room dimensions, a "standing" wave can be set up in this dimension, in which case the sound in the room behaves rather like a pendulum whose rate of swing is determined by the length of the room and whose motion tends to persist for a fairly long time. It applies to all three main dimensions of the room - and also to any recess or in combination with furniture wherever facing flat surfaces occur - and even to the diagonals of the room.

For a room of any given size there are a number of sound frequencies which receive enhancement and die out much more slowly than other frequencies. These are called "eigentones" or "normal modes".

The sound pressure of such a normal mode in a room is not uniform across the room but has certain positions in the dimension where the sound pressure level is a maximum and a minimum. If the dimensions of the room are such that a natural eigentone matches incoming low frequency noise from the atmosphere (and in many areas all over the world, in a temperature inversion such low frequency noise is readily measurable), then the room will respond to the sound, creating elevated sound pressure levels at specific positions in the room - thus constituting an enhancement mechanism. Further enhancement results if the sound enters the room (as a large cavity) through a narrow opening such as a small or partially open window [14]. Even so the levels produced from naturally occurring low frequency sound are still very low (in the order of 50 dB in the 31.5 Hz octave band) and inaudible to most people.

However, in Utah, in those rooms in which a SIDS had occurred, every room that could be examined had a normal mode frequency of between 35 and 45 Hz (depending on the temperature), matching those produced inside a small car in motion. Perhaps more relevant, a position of maximum sound pressure was found in the approximate location of the child, as far as can be ascertained from the evidence. Physical excitation and measurement was not possible for obvious (psychological) resaons, although it is hoped that in the near future such may be possible in the right circumstances.

One, of course, may justifiably be skeptical that such a low sound level could set off a chain reaction resulting in death. Elder children (over 18 months of age) are apparently quite unaffected, as are grown-ups, and one wonders how such a noise could affect a small child, if indeed it is the noise that acts as the initial stimulus. With just this one parameter being identified so far in all the 130 cases examined, and no similar occurrence of any of the other parameters examined, it does suggest the possibility of a relationship between the sound and the event. But the author is finding it difficult to plan how best to proceed with the investigation when there appears to be so much antipathy to finding a cause and hence planning preventative measures.

The mechanism for such a noise affecting a child to cause SIDS remains an enigma. But, some years ago, the author investigating an area of severe disturbances from such a low intensity, low frequency sound in the atmosphere, found a possible relation between the geographical limits of the sound disturbance and endemic mild dysentry [15]. Following the research he amplified a recording of the sound (which actually he could not hear at all without significant amplification) and experienced extreme vibration within the head and an immediate significant hearing loss. Little recovery in the succeeding week led to hospital admission and major surgery to repair damage that the author put down to the noise exposure. (Regrettably there is no medical proof of such a causal relationship.) Analysis of the recording located a distinct spectral pattern in the 40 Hz region, a pattern that seems to be duplicated in all the Utah homes examined in connection with SIDS.

This leads the author to believe that natural low frequency sound is a candidate for being the initial stimulus to a chain of events/reactions that lead to Sudden Death in Infancy, if the child is "receptive" to such a stimulus - a behavioural or medical condition or disease. When he experienced the severe internal vibration from the amplified sound - a variation of which, most regrettably, is believed to be in use by the military of several Western powers for crowd control - the author felt that entry was via direct conduction through the skull rather than through the auditory system. Up to the age of about 18 months, a young child's skull is not fully developed and awaits closure of the fontanelle - a condition common to all the SIDS victims examined. This may act as the easy entry point for the low intensity sound wave into the cavity producing slightly amplified sound inside. But at the moment this is pure speculation, for research work involving acoustic examination of the infant cadaver head was refused authorization and has not gone ahead.

The author is well aware that consideration of a mere 130 cases in Utah is circumstantial, hardly representative of the world at large, and by no means can provide valid medical evidence. Much more is required in other countries and states, and research is going ahead in this direction with sound as one of a number of physical parameters being investigated. Any constructive criticism or ideas how best to proceed would be very welcome.

If such a chain of events is involved, the removal or weakening of one of the links could decrease the incidence of this major cause of infant death.

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SOUND ECONOMY

REPORT BY A MANAGEMENT CONSULTANT ON A CONCERT AT THE ROYAL FESTIVAL HALL, LONDON

For considerable periods the four oboe players had nothing to do. Their numbers should be reduced, and the work spread more evenly over the whole concert, thus eliminating peaks and troughs of activity. All twelve violins were playing identical notes. This seems unnecessary duplication. The staff of this section should be drastically cut; if a large volume of sound is required it could be obtained by means of an electronic amplifier.

Much effort was observed in the playing of the demi-semi- quavers. This seems an excessive refinement. It is recommended that all action should be rounded up to the nearest semi-quaver. If this were done, it should be possible to use trainees and lower grade operatives more extensively.

There seems to be too much repetition of some musical passages. Scores should be drastically pruned. No useful purpose is served by repeating on the horns a passage which has been handled by the strings. It is estimated that if all redundant passages were eliminated, the whole concert time of two hours could be reduced to twenty minutes, and there would be no need for an interval.

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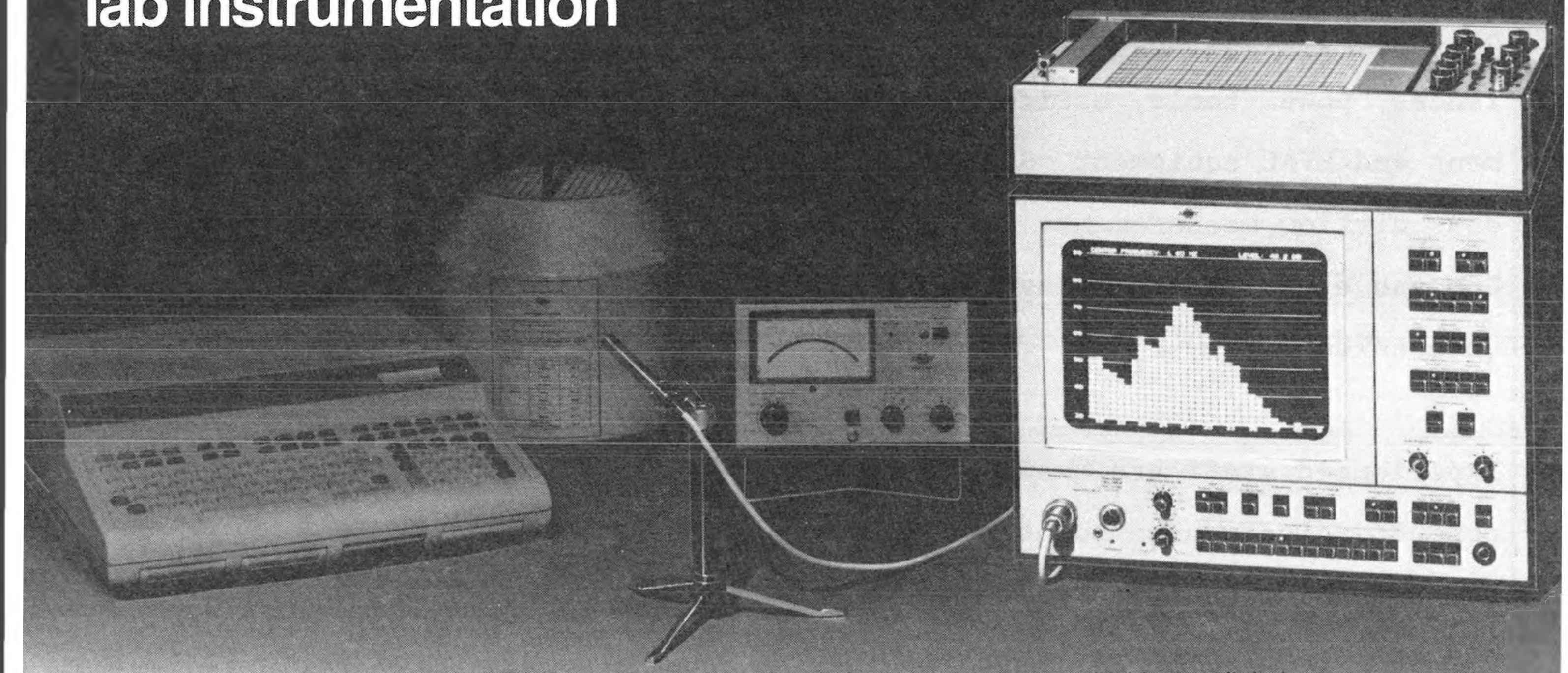

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METHOD AND INTERPRETATION OF SURVEYS ON NOISE ANNOYANCE

Frank Krammer
Noise Pollution Control Section
Environment Ontario

ABSTRACT

Major practical considerations during the design and analysis of sociological noise surveys are briefly discussed, particularly as they relate to choice and interpretation of statistical tests. The discussion concentrates on the appropriate use of data and scale transformations which may not only assist in the interpretation of results but also clarify seeming discrepancies both within a study as well as between apparently conflicting results reported in the literature. Applicable scale transformations are supported by the specification and discussion of theoretically based quantitative functions which may be used to predict human response from noise-level measures of loudness.

The interest of the Noise Pollution Control Section of Environment Ontario in the results of sociological noise surveys is primarily to validate the use of a noise descriptor as an indicator of individual reaction (relative to the Model By-Law) or as a predictor of community impact (relative to land use guidelines and approval criteria). In addition, the choice and effectiveness of noise control measures may be better evaluated with an understanding of differences in sensitivity of people resulting from observable differences in demographic situations. Social surveys are used to answer such questions.

SURVEY PROCEDURES

The statistical analysis and interpretation of a survey are influenced by each step taken during the survey:

1. PROBLEM DEFINITION

The type of analysis will depend on the hypothesized relationships between noise impact or disturbance and noise or other predictors, and the level of qualitative or quantitative information contained in the obtained data.

2. QUESTIONNAIRE DESIGN AND CODING

Questions are carefully worded and placed in the appropriate context to elicit responses that are meaningfully related to the underlying disturbance or impact, so that statistical analyses will have the desired meaning. Questions are therefore very specific to minimize misinterpretation and simplified to assure they are within the capability of the individual to answer.

For example, in a pilot study, people who were asked: Would you say this neighbourhood is quiet, noisy or neither?" sometimes rated their neighbourhood on a busy-quiet, or active-boring scale. The revised question: "Is it generally quiet or noisy in this neighbourhood, or is it neither?" avoided some of the confusion but was often a reportedly difficult decision to make. Many answered that it was sometimes noisy and sometimes quiet and that integration over different situations was difficult.

Allowable answers are coded to represent the underlying scale at a level of measurement as near as possible to that assumed by the statistical test. The fundamental assumption of statistics is that events may be assigned numbers which are values of a "random variable" which in turn is assumed to have specific statistical properties. The number codes are the values of the random variable assumed for the test.

For example, the coding for the previous question on neighbourhood noise would be:

1. quiet
2. neither
3. noisy

reflecting an increased degree of perceived noisiness on a rank-ordered scale. In other words, the value of the code increases with an increase in the factor measured. The number of points chosen for the scale will depend on the respondent's ability to make the judgement, the level of subsequent analysis and the anticipated range of responses. In general, a somewhat finer scale than that required will be chosen since the range of responses is hot known a priori. A detailed scale can later be transformed to a cruder scale but a crude scale cannot be changed to a detailed one, e.g. 1-4 agreeable
5 neutral
6, 7 somewhat disturbing
8, 9 highly disturbing (Hemingway and Krammer, 1977).

Having assured that the question is meaningful and that the codes represent an underlying scale, we would also like to assure that different people use a similar criterion for making the judgement. For example,the respondent may be asked to make the judgement of noisiness with respect to other neighbourhoods in the same city or town. Alternatively, one of the scale points (e.g. ratings) may be more precisely defined, so that other judgements can be made in relation to it.

3. SAMPLING OR CHOICE OF SITES

The choice of sites and of respondents within these sites will determine the generality of the statistical results, as well as the amount of unwanted variability in the data due to the presence of extraneous effects. As a rule of thumb, there must be differences in factors that will subsequently be examined in the statistical analysis. The range of these should be sufficient to include the range over which the hypothesized relationship is to be confirmed. Factors that are not relevant to the problem under investigation, on the other hand, are either kept constant as much as possible or are included as a random component in the statistical model by the choice of a larger (also more costly) sample.

Different statistical analyses assume different methods of sampling. For example, correlation analysis assumes that both variables or factors are random variables, or in other words that the investigator exerts no control over the value that these measures assume. For regression analysis alternatively, values of the independent variable or the predictor of human reaction, is assumed to be predetermined. Minor violations of these assumptions are routine and commonplace, but major violations can be serious.

4. COST EFFECTIVENESS

Sampling is usually the greatest factor influencing cost. Travel costs may be reduced by restricting the physical area to be surveyed. Also, the number of questions asked may be reduced to only those which will relate to the problems of interest.

5. INTERVIEWER TRAINING

Interviewers are trained to administer the questionnaire consistently, interpreting questions as intended.

6. PILOT STUDY

A pilot study points out problems in administration and permits final clarification, or final necessary ...

7. REVISIONS OF QUESTIONNAIRE

8. DATA COLLECTION

Noise data are usually collected after the survey to avoid respondent biases that may result from previous knowledge of the study.

9. DATA CODING

Data is coded on the questionnaire or the information transferred onto a coding sheet which permits easier keypunching. Care is taken that codes define a variable meaningfully as mentioned earlier. (see Table I)

10. KEYPUNCHING

The codes are transferred to a specific set of card columns for each variable. This set is called a "field". Each questionnaire makes up a "record", one for each respondent. Each record is constructed the same way and will have only different codes for the value of each field.

	RESPONDENT	SITE		NOISE RATING	VOLUNTEERED	L_{EQ}		S.D.	
RECORDS (CARDS)	1	1	1	2	2	6	1	4	2
	2	1	1	3	2	6	1	4	2
	3	1	1	1	1	6	1	4	2
	4	1	1	3	1	6	1	4	2
	5	1	1	1	1	6	1	4	2
	6	1	1	1	2	6	1	4	2
	7	1	1	5	1	6	1	4	2

FIELDS

Table I. Sample of a coding sheet, showing the format in which information is handled by the computer.

11. COMPUTER FILE STRUCTURE

The cards are read into computer storage records, each record being a sample. The use of the SPSS package program will be assumed here. The names of the variables are written in the order in which the fields appear on the record, on a "variable list" card. A "format" card specifies the number of columns that are to be read for each variable. (see Table I)

12. DATA TRANSFORMATION

(a) Definition

This is probably the most useful method used by statisticians. The variables defined in the questionnaire are by no means the only variables that can be analysed from the data. For example, a new variable could be truncated to provide fewer scale points. Or, a variable could be defined as a combination of the variables obtained directly from the coded answers as in a count of the number of ways disturbed, the occurrence of any noise disturbance, and the combination of disturbance reports (as obtained from factor analysis, for example) that would most closely approximate the underlying human reaction that is of interest. Also, a functional transformation can be made. For example, a logarithmic transformation on the dependent variable will make an exponential function linear with the transformed variable or a squared transformation will make a parabolic function linear, allowing standard statistical tests to be used.

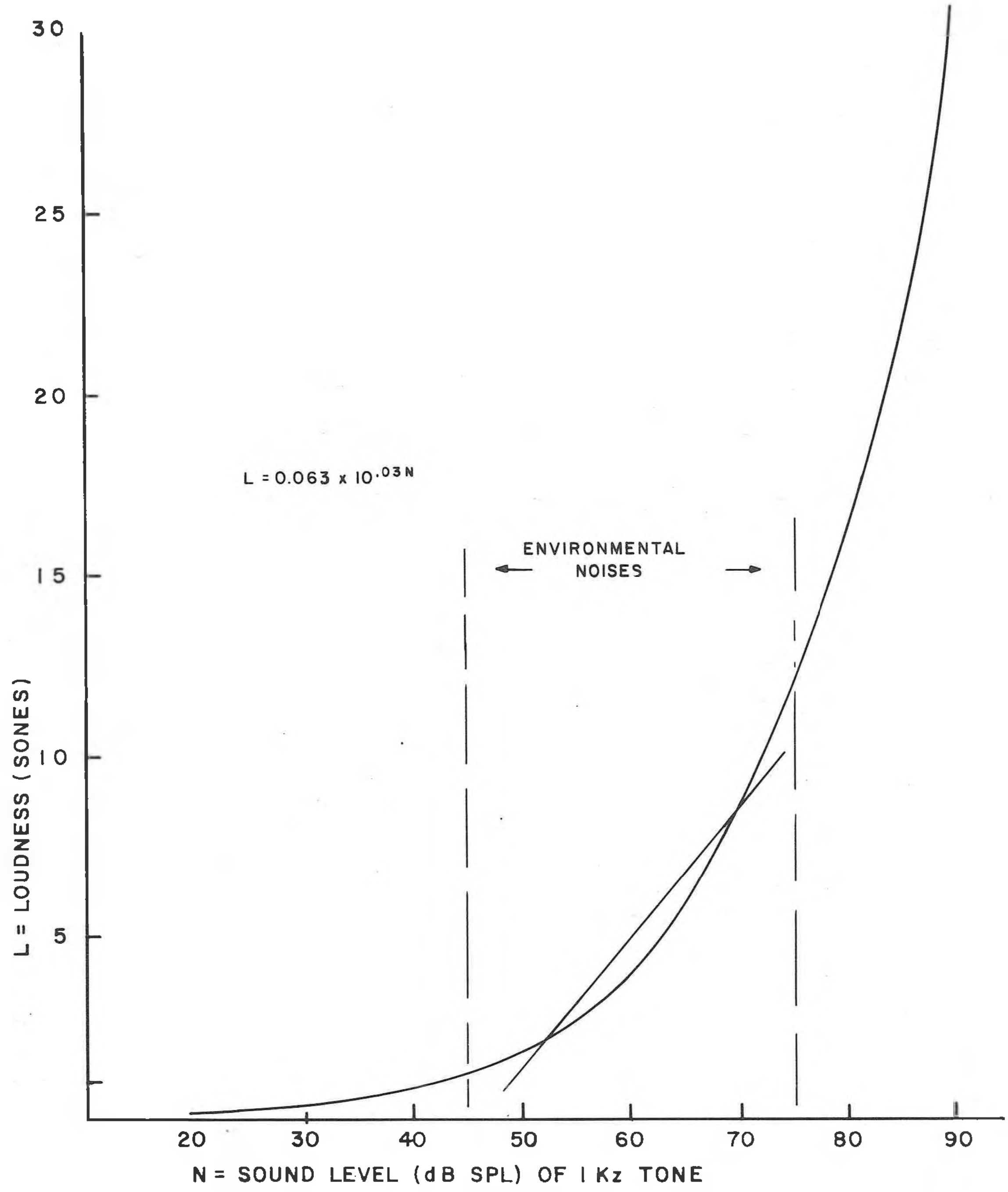

Fig. 1. Antilogarithmic form of the power function of loudness with sound intensity. The graph shows that, within the range of environmental noise levels, a linear approximation may be adequate.

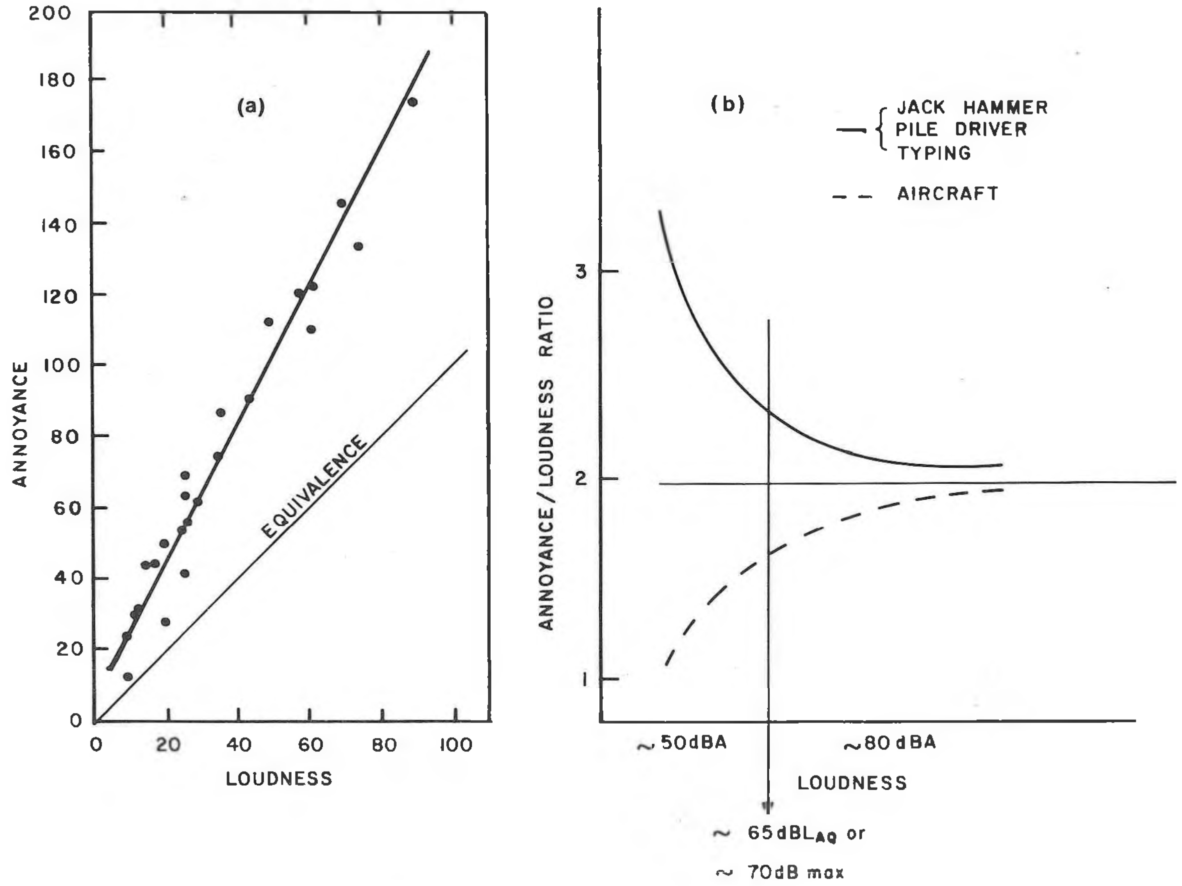

Fig. 2. Somewhat schematized relationship between annoyance and loudness (from Berglund et al ,1976). The perceived annoyance is always greater than the perceived magnitude of the loudness.

(b) Application - Theoretical Nonlinearities

An important underlying relationship is that between noise level and annoyance. The relationship between sound intensity and loudness is accepted as being a power function and therefore roughly an exponential function with the logarithmic sound level scale (see (Fig. 1). From work by Berglund et al (1976) annoyance appears to be linearly related to loudness (see Fig. 2 (a)). Therefore, annoyance may also be basically an exponential function of sound level.

The underlying relationship between sound level and annoyance should then be roughly exponential. In the Berglund et al (1976) study, the sources examined were about twice as annoying as they were loud at levels over about 70 dBA. At lower noise levels, the levels of annoyance relative to loudness appeared to depend on the source of the noise (see Fig. 2 (b)). Preliminary results by Hall, Breston and Taylor (1977) also suggest a possible underlying relationship of reduced house prices with increased noise levels, significant differences in house prices being observed only at sites with noise levels greater than about 70 dBA L_{eq}.

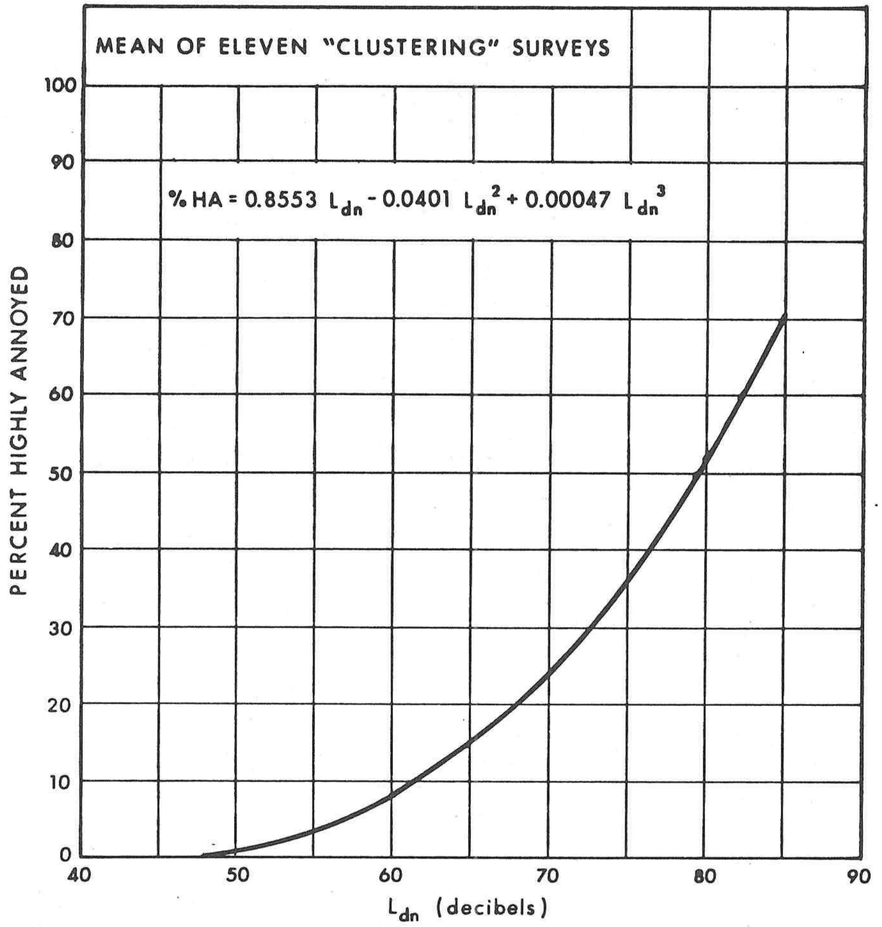

Fig. 3a. Schultz's synthesis of survey results. The mean of data from eleven surveys, shown here, has been proposed as the best currently available estimate of public annoyance due to noise of all kinds. (from Schultz, 1978)

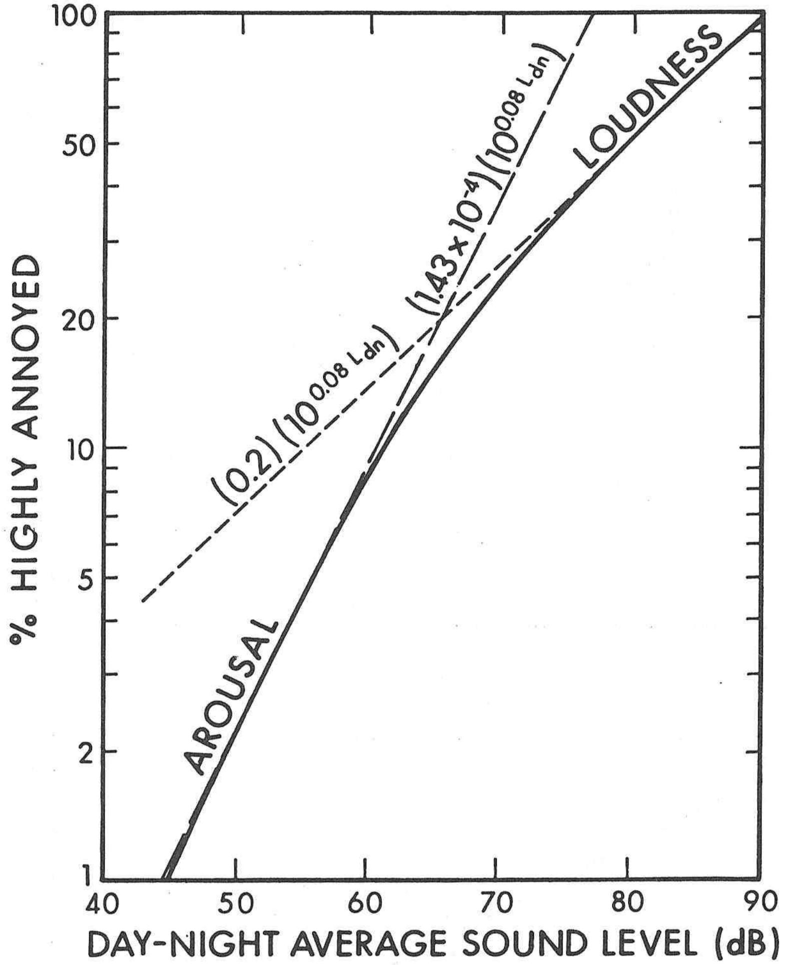

Fig. 3b. Schultz's power function approximation to the cubic equation for relating annoyance to day-night average sound level. (from Schultz, 1978)

If this relationship is indeed exponential, then the relationship between sound level and the logarithm of annoyance should be approximately linear. In other words, a constant difference in noise level should be related to a proportional increase in annoyance. For example a 10 dB increase is about twice as loud and possibly roughly twice as annoying on average.

(c) Application - Theoretical Interpretation and Extension of Survey Data

In addition, some evidence of a nonlinear relationship between sound level and percent highly annoyed for grouped data is reported by Schultz (1978b), as reproduced here in Fig. 3. Despite the initial resemblance of the curve to an exponential relationship, however, this nonlinearity is not expected to and does not follow the same relationship as degree of annoyance with sound level. This underlying relationship is most reasonably assumed to follow the cumulative normal distribution, as originally proposed by Fechner (1860), who suggested that the conversion of response frequency data to normal deviates should provide a straight line when plotted against the physical parameter in his psychophysical experiments.

Another way of regarding the synthesized sociological survey data of Schultz (1978b) is to consider the best estimates of percentage highly annoyed at various noise levels as sample estimates of the underlying probability of high annoyance at these noise levels. The true probabilities should follow a statistical distribution. The most reasonable first assumption is that it is the cumulative normal. The normal sigmoid curve may be changed to a straight line by applying a probit transformation to an ordinate in percentages or probabilities (see Fig. 4(a) and (b)). The probit scale is simply a scale in which each unit is a normal equivalent deviate (N.E.D.), or a standard deviation of the applicable normal distribution. In Fig. 5, Schultz's (1978b) synthesized curve is plotted with a percentage scale linear in probits. From Fig. 5 it is obvious that the relationship is effectively linear. The relevant curve describing Schultz's (1978b) synthesis is therefore the cumulative normal curve with mean about 79 dB and standard deviation about 13 dB.

A more precise specification of these parameters may not be advisable without direct access to Schultz's synthesized data. In other words, the synthesized model is purposely descriptive whereas the proposed model is desired to be theoretically valid. Specifically, the least squares criterion of the descriptive regression fit will tend to assign less weight to low (or high) values of the grouped (percentage) observations than to intermediate values. As put by Finney (1971, p.180), "grouped data tend to underestimate the slope of the line, which should be drawn so as apparently to err slightly on the side of steepness."

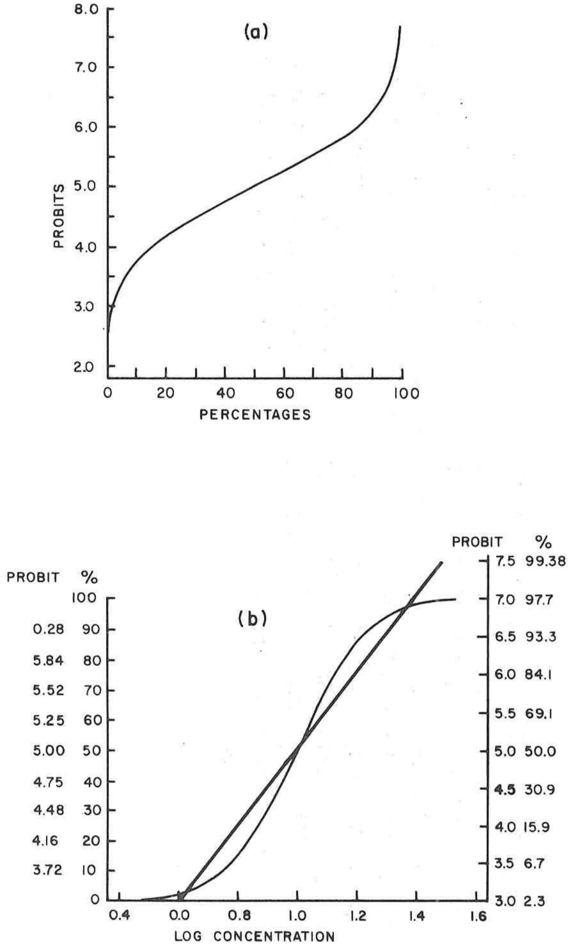

Fig. 4. When the probit transformation shown in (a) is applied, the normal sigmoid curve is transformed to a straight line as shown in (b) when ordinates are on a scale linear in probits instead of percentages. (from Finney,1971,pp.23-24)

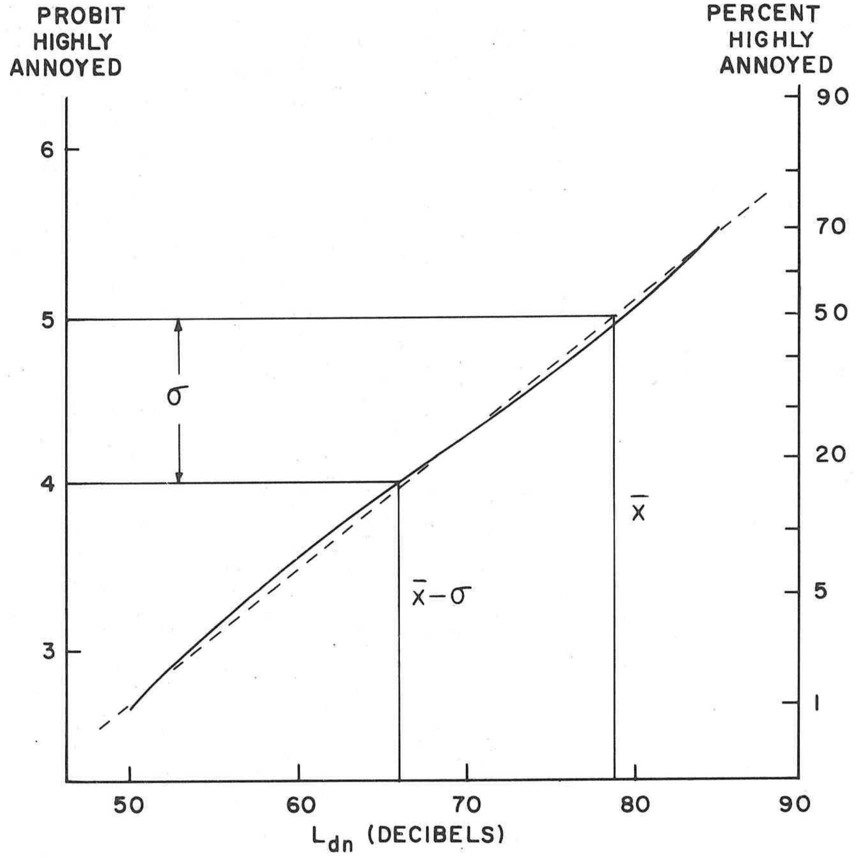

Fig. 5. Schultz's (1978) synthesized survey results plotted with a probit transformation of the percentage scale of annoyance.

The proposed theoretical sigmoid function has both theoretical and practical advantages over Schultz's descriptive model. For example, it is more reasonable to extend a theoretical curve to include lower and higher noise levels (as recognized by Schultz, 1978a). Also, apparent discrepancies in results may be clarified. Referring to Fig. 4(b), we note that responses of between 20 and 80 percent are effectively described by a linear model. The bias of percentage estimates toward decreased slope is unlikely to be of practical significance unless the line is extrapolated beyond this sample space of the range of predictor (independent) variables. On the other hand, if response probabilities (or percentages) are frequently lower than 20 and higher than 80 percent use of a probit transformation may be effective. For example, low response probability is expected for "highly disturbed" ratings or "low-noise" sites (e.g. arterial traffic) and high response probability, for "somewhat disturbed" ratings or "high-noise" sites (e.g. freeway traffic). In such situations, the researcher commonly obtains anomalous results as a lack of significance on statistical analyses.

Unfortunately, probit transformation can only partially rectify the handling of such extreme data. Two reasons are the bias of grouped estimates previously noted and the fact that probits of 0 and 100 percent are not defined, although ways of dealing with these problems are available. One solution is to perform the analysis directly on individual data as opposed to analysing grouped estimates obtained from this data. The most appropriate analysis of such data, particularly when several predictors are considered simultaneously, appears to be probit or logit analysis, as previously applied to similar questionnaire data (Ugge, 1977; McCafferty, 1978).

13. STATISTICAL ANALYSIS

The analysis is performed on data structured as in Table I. Practically, nonparametric statistical tests are performed on data assumed to be on an interval-scale level (i.e., equal units) or better. For example, the percentage scale is effectively not an interval scale of annoyance or other human reactions at its extremes. Also since this scale is bounded at its extremes, the "homogeneity of variance" assumption of commonly used tests is violated (without probit transformation), the variability of extreme values being restricted. The bias is expected to be toward increased significance and decreased slope of a regression (or least-square fit) line. Nonparametric statistics are more safely used when the researcher lacks confidence in the parametric characteristics of his data.

To the reader unfamiliar with the field of applied statistics, lest the negative tone of the previous discussion be overinterpreted, it must again be stressed that the violation of statistical assumptions is routine, most popular tests being relatively insensitive to minor violations. The caution applies to the case of a researcher unintentionally violating these assumptions and consequently falsely interpreting statistical results.

SAMPLE OF 30 (GROUPED)

INTERCORRELATION OF NOISE DESCRIPTORS

		.95	.9	.8	.7
DIFFERENCE ($.6-C_L$)	.05	X	X	X	X
	.1	SIG	X	X	X
	.15	SIG	SIG	X	X
	.2	SIG	SIG	SIG	X
	.25	SIG	SIG	SIG	SIG

SAMPLE OF 300 (INDIVIDUAL)

INTERCORRELATION OF NOISE DESCRIPTORS

		.95	.9	.8	.7
DIFFERENCE ($.4-C_L$)	.02	X	X	X	X
	.05	SIG	SIG	X	X
	.075	SIG	SIG	SIG	X
	.1	SIG	SIG	SIG	SIG

Table II. Significance of differences between correlation coefficients, based on typical intercorrelations of noise descriptors and sample sizes used in sociological surveys (c_L = correlation coefficient of lower value; significance level: $p \leq 0.05$ for two-tailed test).

14. INTERPRETATION OF RESULTS

This final step of the survey encompasses all previous steps, as already noted. As a simple illustration, a statistical treatment of a controversial topic is illustrated in Table II. The topic is the choice of the "best" noise descriptor. The basis for the choice, statistically, is the significance of differences between correlation coefficients of various noise descriptors with a selected measure of human reaction. Practically, however, one faction reports all differences as being (non-statistically) significant. The opposing faction may cast doubt on all differences. A third faction may consider the problem of no consequence since all noise descriptors are highly intercorrelated in any case and human reactions much less so. Although the final conclusion must inevitably be based on a philosophical premise, the objective basis for the decision is significant by its absence in all reports coming to this author's attention. Therefore it is presented here (Table II).

It is of interest to observe that higher intercorrelations between noise descriptors give greater confidence to observed differences in correlation coefficients with human reaction. Differences as small as 0.15 or less may be judged statistically significant when noise descriptors near freeway sites are compared in the manner described.

If the data is analyzed individually, confidence in the smaller obtained value of the correlation coefficient is greater, differences as little as 0.05 being statistically significant. In addition, the statistical significance of the correlations themselves relative to correlations of grouped data are considerably more significant (from studies: Hemingway and Krammer, 1977; Seshagiri and Krammer, 1976), allowing more confidence to be placed in the existence of a relationship. Please note that the smaller coefficient is the more powerful here and that this comparison is between two different dimensions. For grouped data, the dependent variable is probability (observed percentage) of disturbance at or greater than a defined criterion. For individual data, the relevant measure is degree of disturbance. The justification for their comparison is the close agreement of results obtained by each method (Hemingway and Krammer, 1977; Seshagiri and Krammer, 1976). Also, individual ratings may be truncated at the same criterion used for grouped data. The primary objection to the analysis of the original individual data is that the measure of individual disturbance may not represent an interval-level scale and that quantitative data may therefore be suspect. Nevertheless, emp rically, it is the ratio of the random error (largely due to individual differences) to the scaling error that is more directly relevant to the interpretation of results.

SUMMARY

Major considerations relevant to statistical analyses and their interpretation have been discussed under the following headings:

1. Problem Definition
2. Questionnaire Design and Coding
3. Choice of Sites (Sampling)

4. Consideration of Cost Effectiveness
5. Interviewer Training
6. Pilot Study
7. Revision of Questionnaire
8. Data Collection
9. Data Coding
10. Keypunching
11. Computer File Structure
12. Data Transformation
13. Statistical Analysis
14. Interpretation of Results

Recognition of the considerations discussed was viewed as the major factor determining the success of a survey. The choice of a specific methodology on the other hand, was viewed as an optimization of such considerations as they relate to the specific application. The successful interpretation of results was viewed as a product of the recognition of inevitable weaknesses in methodology and the elucidation of theoretical and philosophical assumptions.

A companion paper will express the assumptions discussed here as a mathematical theory. Theoretical fits and interpretations of social survey data and their application to the synthesis of social survey data and the estimation of noise impact on people will be discussed in further follow-up reports.

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Yard Surveys (Seshagiri and Krammer, 1976; Seshagiri, 1977; Krammer and Dixit, 1979) and during the computer analysis and interpretation of results phases of the Metro Toronto Survey (Hemingway and Krammer, 1977) on annoyance to community noise.

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THEORETICAL MODELS FOR RELATING ANNOYANCE TO NOISE LEVEL

Frank G. Krammer

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Environment Ontario

ABSTRACT

Theoretical mathematical models are formulated to specify the relationship between human annoyance and levels of noise, based only on well confirmed assumptions. The proposed theories are consistent with descriptive models and appear capable of explaining the underlying mechanism as well as previously apparent discrepant findings.

THE MODELS

From experimentally supported theoretical assumptions discussed previously (Krammer, 1979b) and the assumption that a complex continuous sound is equivalent to the loudness of a reference stimulus (e.g. a 1-kHz tone) if both are equivalent on appropriately weighted sound levels, the following models of human reaction to sound level are derived, converting

(a) Sound level $\underline{N}$ to loudness $\underline{L}$:

$$L = k10^{0.03N} = k\,(1.0715)^{N} \qquad (1)$$

where $\underline{k}$ is an arbitrary scale factor.

(b) Sound level $\underline{N}$ to individual annoyance $\underline{A}$:

$$A = a\ k\ 10^{0.03N} + b = a\ k\ (1.0715)^{N} + b \qquad (2)$$

where $\underline{a}$ is the asymptotic annoyance to loudness ratio, $\underline{A/L}$, and $\underline{b}$ is the A-intercept of the curve relating annoyance to loudness. Preliminary experimental findings suggest that $\underline{a}$ is relatively constant and independent of type or quality of noise, but that $\underline{b}$ is a correction factor dependent on type and quality of noise (Berglund et al, 1976).

(c) Probability P or expected percentage 100P of individual or community reaction to noise R respectively, given the noise level (N):

$$P\,(R|N) = \int_{-\infty}^{N} \frac{1}{\sigma\sqrt{2\pi}} \exp\left[\frac{-(n-\mu)^2}{2\sigma^2}\right] dn \qquad (3)$$

where R is annoyance at or greater than a predefined criterion, and n is the random variable of the theoretical normal probability density function, with mean u and standard deviation o, which describes the probability density of the specific annoyance reaction at specific noise levels.

Parameters of these functions may be obtained from experimental work. Parameters included below are purposely approximate but may be more precisely specified as confindence in experimental observations increases. With substitution of available parameter estimates, the previous models may be somewhat simplified, e.g. converting:

(a) Sound level N to loudness L :

$$L \text{ (in sones)} = 0.063\,(10^{0.03N}) \qquad (4)$$

where "0.063" is the scaling factor for the sone scale.

(b) Sound level N to annoyance A :

$$A \text{ (re sones)} = 0.126\,(10^{0.03N}) + b \qquad (5)$$

where a=2 (from Eqn. B), approximated from the Berglund et al (1976) data, and the sone scale is implied. From this function it is obvious that the lower the noise level, the greater the relative contribution of the constant b, which may potentially be estimated from experimental data.

(c) Probability P or expected percentage 100 P of individual or community reaction R to noise level N :

$$P(R|N) = \int_{-\infty}^{N} 0.0307 \exp\left[\frac{-(n-79)^2}{338}\right] dn \qquad (6)$$

$$= \int_{-\infty}^{N} 0.0307\,(.997046^{(n-79)^2})\,dn$$

assuming R is a "highly annoyed" reaction and N is L_{dn}, both as defined by Schultz (1978a, 1978b).

DISCUSSION

The effect of time-varying properties of noise on human response has not yet been clarified and remains an area of continuing study and discussion (Seshagiri and Krammer, 1976; Hemingway and Krammer, 1977). Major studies examining the problem have arrived at opposite or no linear relationships between noise variability and annoyance. That is, both positive and negative relationships (Robinson, 1971; Bradley, 1977) have been reported. A recent study by Hemingway and Krammer (1977) has observed evidence of both relationships in the same study. A U- or inverted bell-shaped function has been proposed as a tentative working hypothesis (Hemingway and Krammer, 1977; Krammer, 1978) to describe human reaction to variability of noise level over time. Recent analyses (Krammer, 1979c), however, suggest that the form of this function may depend on noise source and time of day. In other words, the present working hypothesis requiring further testing is that both the time history function of noise levels and whether or not the exposed individual is awake or asleep may interactively affect annoyance ratings. Such factors are tentatively judged to be most effectively included in the source dependent term $\underline{b}$ of the annoyance model (Eqn. 2) for reasons that will be discussed in a later report.

CONCLUSIONS

Theoretical mathematical models derived only from basic assumptions appear to become reasonably complete when parameters are estimated from experimental data. In the equations relating annoyance to sound level, only one parameter is notably absent, but open to empirical estimation. In their present form, the discussed models provide plausible explanations of observations which have previously been considered unusual or discrepant, and allow for greater ease of generalization of future data. Potentially, they also provide a framework for the prediction of that portion of human reaction determined by the physical properties of noise.

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