A prediction and study of noise as related to truck drivers' exposure.

Arthur E. Steevensz

University of Windsor

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A PREDICTION AND STUDY OF NOISE
AS RELATED TO TRUCK DRIVERS' EXPOSURE

BY

ARTHUR E. STEEVENSZ

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES THROUGH THE
DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FILFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF APPLIED SCIENCE AT THE
UNIVERSITY OF WINDSOR

WINDSOR, ONTARIO, CANADA
1982
TO MY MOTHER, DEARLY DEPARTED FATHER,

RICHARD AND SHIRLEY
ABSTRACT

In-cab noise exposure by operators in commercial diesel tractor-trailers and buses was surveyed. A miniature microphone of special design was used for this purpose; it was sufficiently small to be placed within the ear. Two microphones were mounted on the left and right ear within the cavum of the concha where measurements are least affected by extraneous effects. Another microphone was located at the center of the cab.

The noise was recorded continuously on cassette tape throughout the operator's normal work day. The data were later analyzed in the lab.

In-cab measurements were also conducted with the standard procedures: CSA Z107.23 and SAE J366a. CSA Z107.23 measures the in-cab noise while the vehicle is stationary and SAE J366a, when the vehicle is accelerated in a prescribed manner.

The results indicate that the potential for excessive noise exposure is highest during freeway driving and decreases for highway and city driving in that order. The sound level at the left ear is on average 6dB higher than at the center of cab position. The use of CB radio or even normal radio significantly increases permanent hearing loss hazard. An equation is also derived to predict the operator's noise exposure without the use of noise dose meters.
ACKNOWLEDGEMENTS

The author would like to acknowledge his sincere appreciation to Dr. Z. Reif for his understanding, patience and valuable guidance during the course of this study.

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  Kingsway Transportation Limited
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  Kovinsky and Sons Limited

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He further wishes to thank many of his colleagues who have rendered any assistance in this research programme and Ms Jacqueline Langlais for her assistance in the production of this thesis.
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NOMENCLATURE

\( a \)  \quad \text{Y-intercept linear regression (Z)}

\( a' \)  \quad \text{Linear regression slope}

\( ac \)  \quad \text{Alternating current}

\( b \)  \quad \text{Linear regression slope (Z)}

\( b_1, b_2, b_3 \)  \quad \text{Y-intercept linear regression (dBA)}

\( C_n \)  \quad \text{Actual Time spent in the nth sound level (min, hrs)}

\( c \)  \quad \text{Y-intercept linear regression (Z)}

\( d \)  \quad \text{Linear regression slope}

\( dc \)  \quad \text{Direct current}

\( E_s \)  \quad \text{System's error (dBA)}

\( E_x \)  \quad \text{Errors of associated equipment to determine the magnitude of the measured parameter (dBA)}

\( E_i \)  \quad \text{Microphone location error (dBA)}

\( E_{MT} \)  \quad \text{Combined microphone and tape recorder error (dBA)}

\( E_B \)  \quad \text{Body baffling error (dBA)}

\( e \)  \quad \text{Y-intercept linear regression (Z)}

\( f \)  \quad \text{Slope linear regression}

\( H \)  \quad \text{Height (mm or in)}

\( ips \)  \quad \text{Inches per second}

\( K \)  \quad \text{Y-intercept linear regression (hrs)}

\( L \)  \quad \text{Length (mm or in)}

\( L_{eq} \)  \quad \text{ISO R1999 A-weighted equivalent sound level (dBA)}

\( L_i \)  \quad \text{ith sound level (dBA)}

\( L_{os} \)  \quad \text{OSHA A-weighted equivalent sound level (dBA)}
$L_n$ scan

Plot of percentile level (Z) on the vertical axis versus sound level on the abscissa (dBA)

$L_p$

Sound level (dBA)

LED

Light emitting diode

$m_1, m_2, m_3, m_4$

Slope linear regression

N

Number of samples

ND

Noise dose (Z)

ND_city

Noise dose of exposure during city driving (Z)

ND_highway

Noise dose of exposure during highway driving (Z)

ND_freeway

Noise dose of exposure during freeway driving (Z)

ND_ISO

Noise dose of exposure based on ISO R1999 regulation (Z)

ND_OSHA1C

Noise dose of exposure based on OSHA1C regulation (Z)

ND_POIR

Noise dose of exposure based on POIR regulation (Z)

ND_predicted_8_hours

Predicted noise dose for 8 hours (Z)

ND_8_hours

Noise dose for 8 hours (Z)

$P_0$

Reference sound pressure ($2 \times 10^{-5}$ N/m$^2$)

$P_m$

Sound pressure (N/m$^2$)

$P(t)$

Time varying sound pressure (N/m$^2$)

$P_1$ scan

Plot of percent of time (Z) versus sound level (dBA)

$q$

Number of dBA to be added to the noise level to give the same noise dose if the duration is halved (dBA)

$r$

Linear correlation factor

$t, T$

Time (hours, minutes)

$T_n$

Time of the nth parameter (hours, minutes)

$T_{city}$

Time of noise exposure during city driving (hours, minutes)

$T_{highway}$

Time of noise exposure during highway driving (hours, minutes)
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CHAPTER I

INTRODUCTION

1.0 General

Transportation of heavy goods by road requires drivers to operate their vehicles for long and short distance deliveries. Particular problems confronted by these operators are those associated with the noise and vibration of their working environment. Such exposure creates both an annoying and tiring effect on the driver.

A recent survey conducted by Statistics Canada (*) indicates that there are approximately 5 million people employed in transportation which includes air, water, surface and other material handling methods. It is estimated that there are nearly 2 million people involved in driving trucks. Of these a high proportion operate large trucks on a regular basis.

The fact that there are many truck drivers brings about a concern for the operator's noise exposure. A well known fact indicates that exposure to diesel truck noise at a high enough level, for even short periods, will often cause temporary hearing impairment with eventual recovery to normal after the noise ceases. The most significant effect of prolonged exposure to high noise levels is permanent loss of hearing.

The noise exposure of truck drivers in normal commercial runs has not been systematically investigated. This project is intended to

(*) Numbers in parenthesis refer to publications in the List of References.
provide information on several aspects of in-cab noise conditions and their effects on the driver.

1.1 Scope

A brief outline of the objectives of this project is given as follows:

(a) To monitor and investigate the noise exposure levels of drivers operating buses (public and school), heavy trucks exceeding 30,000 lbs. The exposure is recorded during the actual driving time and under various modes of driving encountered during the hauling period. The modes of driving are divided into three segments: city, highway and freeway driving. The recordings are evaluated according to the present noise regulation standards namely ISO-R1999, Assessment of Occupational Noise Exposure for Hearing Conversation Purposes, (cut-off range 80-130 dBA) and OSHA-90, Occupational Safety and Health Act - OSHA, (cut-off 90-115 dBA). Further study of modified regulations that might be adopted are OSHA-90 (cut-off 85-115 dBA) and POIR-85, Proposed Ontario Industrial Regulation, (cut-off range 80-115 dBA). These criteria are discussed in a later section.

(b) Conduct a stationary CSA Z107.23 (Canadian Standards Association) and a pass-by SAE J366R2 (Society of Automotive Engineers) interior cab test (Appendix C and H).
(c) Correlate the in-cab test with the equivalent noise

$(L_{eq} - dBA)$ levels for the three modes of driving conditions.

(d) To develop a relationship to predict the noise exposure

based on the in-cab test conducted on various tractor-trailers.
CHAPTER II

THE EAR AND ITS PROTECTION

2.0 Introduction

Noise is common and frequent in today's society. The means with which we sense the sound level variations is the ear, something which we generally take for granted. In the following chapter a brief description of this sensitive organ is given and noise conditions which can deteriorate its physiological function are discussed. Industrial noise regulations, which impose limits on permissible noise exposure of industrial workers are also discussed.

2.1 Mechanism of Hearing

A cross-section of the human ear is shown in Figure 1 with the simplified schematic of the cochlea as it would appear when unwound. The propagation of sound waves traverse through three parts of the ear namely external, middle and inner ear. Sound waves travel first through the outer ear and auditory canal to a thin membrane, called the ear drum, which vibrates. The vibrations are transmitted to the ossicles consisting of three small bones in the middle ear. The vibration is further transmitted through the oval window to the fluid of the cochlea (the auditory part of the inner ear).

One of the ossicles, called the stirrup, acts like a piston moving fluid back and forth in the rhythm of the sound waves. The move-
ment of the fluid causes the thin membrane within the cochlea (the basilar membrane) to vibrate. This in turn bends the hair cells of the organ of Corti which rests on the basilar membrane. These hair cells are the actual auditory receptors; moving them excites them and produces a generator potential which initiates nerve impulses in the fiber of the auditory nerve. The auditory nerve then carries the pulses to the brain and hearing is thus perceived.

2.2 Auditory Sensitivity

The human hearing range is generally within 10 Hz to 20 KHz. However, auditory response to acoustic energy below 10 Hz (infrasonic region) and above 20 KHz (ultrasonic region) have not been extensively examined. Investigations (2,3,4) have indicated that the ear cannot detect infrasonic acoustic levels except at very high sound levels, whereas in frequencies above 20 KHz the human ear seems to have a substantial decrease in sensitivity.

2.3 Effects of Noise Exposure

The ear can tolerate for a few seconds painful loud noise. Such loud noise can disrupt the organ of Corti or at least cause degeneration of some of its hair cells if continued at long lengths of time.

Exposure to excessive levels of noise will commonly cause a combination of temporary and permanent hearing loss. Noise-induced temporary threshold shift (NITTS) is a condition of "temporary loss of hearing", however, hearing is restored during a sufficiently long recovery period. Recovery from this type of hearing loss is usually complete.
It may be considered as a fatigue in auditory hair cell function rather than injury. Noise-induced permanent threshold shift (NIPTS) represents a permanent loss of hearing which is not reversible.

The amount of temporary threshold shift (TTS) increases as the noise level increases and as the time duration lengthens. With most industrial noises the loss almost always begins at 4000 Hz where the recovery from TTS is the slowest. Typically noise levels must exceed 60 dB for most people in order to experience any TTS even for long exposures.

2.4 Criteria for Conservation of Hearing in Noise

The cause-effect relationship that results in the impairment of the human hearing has been extensively studied. Perhaps the most complete and authoritative investigation concerning hazardous exposure to noise and the establishment of a "damage-risk criterion" is the report prepared by CHABA, the National Academy of Science National Research Council Committee on Hearing, Bioacoustics and Biomechanics. Basing the results on data relating to temporary and permanent effects on hearing, the committee concluded that a noisy environment is considered to be acceptable if the average NIPTS after ten years is "no more than 10 dB at 1000 Hz or below, no more than 15 dB at 2000 Hz, or no more than 20 dB at 3000 Hz or above" (5). The criterion protects hearing loss in the low frequency on the assumption that hearing acuity below 2000 Hz is critical to speech perception. The Committee further proposed damage-risk contours which impose restraints on frequency content as a function of sound level with time as the parameter. The graphical representation of the damage-
risk contours for 1-octave and 1/3-octave bands are shown in reference 5. Within the permissible time limits the sound levels in the specific spectrum bands must not be exceeded.

2.5 Noise Standards

Several investigators such as Passchier-Vermeer (6), Robinson (7) and Baughn (8) further studied the relation between noise and noise induced hearing loss in order to establish proposals for determining noise safety standards. Methods resulting from these studies were reasonably accurate in predicting hearing damage, however, they were too complex in appraising noise hazards in practice. In simplifying the noise hazard criterion, the decision as to how to relate the sound pressure level to duration was sought.

It is well established that among other variables the hearing hazard is predominantly dependent upon the sound pressure level and duration of exposure. There is also a complex frequency dependence as shown by the 1-octave or 1/3-octave contours of the CHABA recommendation. Their use for real problems was found to be impractical. This difficulty was eliminated by the use of A-weighting which provides acceptable allowance for the frequency dependence.

On the basis of information available several years ago three theories were established and are listed below.

(a) Equal energy (ISO) - a relationship in which the sound level varies inversely as 10 log(t) (where t is the time duration in hours). This predicts that the sound level must be reduced by 3 dB for each doubling of duration.
(b) Equal pressure (Kryter) a relationship in which the sound level varies inversely as \(20 \log(t)\).
This indicates that the sound level must be reduced by 6 dB for each doubling of time.

(c) Equal pressure (OSHA) - a compromise between ISO and Kryter suggests a 5 dB reduction for each doubling of duration. In this case the sound level varies inversely as \(16.6 \log(t)\).

From these theories two main hearing conservation standards were developed, namely the ISO-R1999 and the OSHA regulations (refer to Figure 2). These form the basis for several modifications which are listed below:

(i) The equal energy rule relates the ISO-R1999 regulation with cut-off limits 85-125 dBA, and is most widely used throughout Europe. The regulation follows the rule that permits eight hours at 90 dBA for 100% exposure and reduces the allowable time by one half for each \(\frac{1}{2}\) dBA increase in noise level. Permissible exposure must not exceed 100%. This criterion will be referred as ISO-R1999.

(ii) The OSHA regulation is used in North-America with cut-off limits 90-115 dBA. As previously indicated the rule permits eight hours at 90 dBA for 100% exposure and reduces the allowable time by one half for each 5 dBA increase in noise level. Permissible exposure must not exceed 100%. This criterion will be referred to as OSHA1A.

(iii) Recently the range was extended to 85-115 dBA to allow
for overtime and is referred to as OSHA1B. 100% exposure still corresponds to 8 hours at 90 dBA.

Currently available information indicates that hearing protection regulations do not adequately protect workers who are particularly susceptible to noise. Hence, new noise proposals have been considered and are as follows:

(iv) OSHA1C, similar to OSHA1B except the cut-off range is 75 dBA to 115 dBA.

(v) A new regulation is considered for introduction in the Province of Ontario. It permits eight hours at 85 dBA for 100% exposure and reduces the allowable time by one half for each 5 dBA increase in noise level. The regulation has no cut-off limits and will be referred to as Proposed Ontario Industrial Regulation (POIR).

It is thus noted that POIR is more stringent than OSHA1A regulation.
CHAPTER III

LITERATURE SURVEY

3.0 Introduction

Noise exposure levels of diesel truck drivers, which were almost undocumented ten years ago, are now a major topic for anyone interested in automotive design. As yet, there exist only a few studies on the subject. An overview of past and recent studies is discussed in this chapter on in-cab noise in vehicles, including passenger vehicles. Discussion of this latter category involves the means of measurement which can be applied towards in-cab truck measurement techniques. The mechanism of noise generated inside the cab is of great interest, since it influences the methods of measurement and noise attenuation design.

3.1 Previous Studies

An early investigation of surface transportation was conducted by Bonvalent (9) 1950, in which interior noise levels were surveyed on subway cars; diesel, steam and electric trains; buses, and trucks. Interior noise measurements were conducted in warm summer conditions with windows open and closed. The readings were taken in the center of the vehicle at "speeds commonly used". The survey indicated that for winter conditions, there is a reduction of noise inside with windows closed. Noise level differences for example between summer and winter conditions range 3 to 10 dB linear.
A great number of interior noise studies were concentrated on automobile perhaps for obvious reasons since a large percentage of people drive cars. Measurements of noise levels inside passenger vehicles have been studied by several investigators. Such studies are pertinent with regards to measuring techniques as well as the analysis aspects. Objective and subjective tests by Robinson et al (7) and Ford et al (10) indicated that interior and exterior sound levels can be correlated by sound pressure instruments with A-weighted network. Underwood and Solomon (11) surveyed noise levels inside passenger vehicles under different driving conditions and on different road surfaces. Their results indicated that: (a) noise levels inside cars vary directly with vehicle speed; (b) all vehicles produce about the same frequency spectrum, where much of the noise lies below 250 Hz and is independent of model or manufacturer; (c) the expressway noise is three times louder than on asphalt and gravel and about six times louder than for idle test.

Exterior passby tests by Olson (12) on trailer trucks indicate that: (a) sound pressure level increases linearly with speed; (b) doubling of weight increases the average sound level by 3.5 dB; (c) the equivalent sound level for acceleration from stand still can be approximated to that of cruising at 40 to 49 miles per hour.

Two most significant studies of interior cab noise are the reports published by the U.S. National Bureau of Standards and U.S. Department of Transport (13, 14). Results are reported on interior and exterior noise measured on a number of various makes and models of trucks currently in service. This information provides a useful survey of data on interior and exterior levels which would generalize typical noise level characteristics of diesel trucks. Interior noise levels were measured
15 cm (6 inches) from the operator's left and right ear under various vehicle operational modes with windows open and closed. The stationary tests (gear in neutral) include: (a) low idle, (b) acceleration from low idle to maximum governed rpm (revolution per minute) with wide open throttle and (c) high idle. In addition to the acceleration and deceleration tests in accordance with SAE J366, simulated city traffic acceleration measurements were conducted.

In-cab noise levels were also investigated by Williams and Tempest (15). The study included new and in-service vehicles with gross weight up to 40 tons. A measurement programme was devised for this investigation which sought relevant data from four main sources namely: (a) new vehicles from the manufacturer, (b) in-service vehicles from trucking firms, (c) random selection of in-service vehicles and (d) correspondence with manufacturers. Initial investigations indicated that much of the high energy noise content was in the low frequency range and in the infrasonic region. Studies conducted on various vehicles included standard speeds of 30, 40 and 50 miles per hour with windows open and closed and, where possible, coasting and driving on different road surface.

The results indicate an apparent increase of sound level in the cab with vehicle speed, with considerable sound energy concentration in the low frequency region. The results also suggested that even with the engine "off" at 50 miles per hour (coasting), the driver is exposed to high levels in infrasound noise in excess of 82.5 dBA.
3.2 Mechanism of Generation of In-Cab Noise

Theoretical and analytical studies on in-cab noise levels of diesel trucks have been conducted by Fiede (16, 17), Mills and Aspinall (18) and Waters (19). Their investigations are discussed in this section.

The noise that the driver perceives is produced from multiple sources which can be categorized in three sections: these are (i) mechanical (ii) road excitation (iii) aerodynamic noises. Some enter the cab as airborne sound either directly or through walls. Others produce vibrations, which are transmitted through the structure to the cab panels and are regenerated inside as noise.

1. Mechanical noise

   (a) **Engine noise** - Engine noise is defined as the noise radiating from the engine structure. It is generated by the rapid pressure rise of diesel combustion and mechanical components of the engine. Primary combustion forces are at fundamental firing frequencies, however the structure responds to all harmonics of the firing frequency. This, of course, excites the valve train, gearing, fuel injection and structural components which add to the overall cab noise level. Also, noise is radiated from engine surfaces such as engine block, oil pan, rocker arm covers and the like.

   (b) **Fan noise** - The fan noise is dependent upon the number of blades and the angular velocity. Other design parameter include blade width, pitch and blade design (sheet metal, air foil, twist blade). Uneven airflow through
2. Road noise

(a) Road surface - Track conditions can generate vibrational excitation within the cab from which noise is generated by the body panels. Tires react to the rough road surface and vibration energy travels through the suspension to the body panels.

(b) Tire noise - Leisure (20) indicated that external A-weighted sound level increases with either an increase in load or speed. Tire noise becomes significant at high road speeds. Variables affecting tire noise are tread design, road surface, wear, speed, inflation pressure and load. The pocket retread design produces a higher noise level, followed by cross-bar tires and then the rib tires. The closed pocket type form a suction cup effect and hence are by far the noisiest of all tread designs. Tires produce a higher sound level on a rough surface than on smooth surface. Tire noise is affected by tire load and inflation pressure in that both influence tread contact with the road. Tire noise level varies directly with tire contact area on the road surface.

3. Aerodynamic noise - Interior noise due to aerodynamic effects is caused by turbulent boundary-layer flow over the vehicle; more precisely unstable shear layers are created. Therefore, the effect of opening windows causes broad band levels to rise. Studies have indicated that the phenomena contributing to noise increase are
due to (a) creation of free shear layers and (b) a Helmholtz resonator where the cabin is the volume and the window is the neck of the resonator.

4. **Exhaust noise** - Exhaust noise is caused by the sudden release of exhaust gases under pressure when the exhaust valves open. It is frequency dependent and is a function of engine speed, number of cylinders and type of engine cycle. The magnitude of noise levels produced is determined by several factors. Noise radiating from a typical exhaust system is comprised of three subsources, which are pipe surface radiated noise, muffler shell noise and outlet exhaust noise.

Mills and Aspinall (18) report that interior noise is primarily an airborne and structure borne phenomenon. Airborne noise is radiated by engine, muffler, turbocharger, fan and the like. Structure borne noise is developed from mechanical vibrations being transmitted into the body and eventually radiated as sound by the panels. Further evidence of this phenomenon is the presence of distinct patterns in the noise distribution inside the cab. This suggests the presence of standing waves characterized by the cab's acoustic properties. Their findings indicate strong vertical vibration patterns but only weak horizontal patterns which indicate strong vibrational transmission. In an experiment where acoustic excitation was applied beneath the floor of the cab, results show that vibrations die out along the side walls. This suggests a relatively strong excitation of the vertical modes of the air space and relatively weak excitation of the horizontal mode. The vibrational modes of the cab are typically of the ring mode type but with small amplitudes which are quickly damped out. The structural vibration contributes little in
comparison with the total noise produced by the engine, exhaust and aerodynamic noises.

Interpretations of the above findings by Mills and Aspinall indicate the cab noise is principally airborne. Cab noise can be reduced in two ways, first by acoustically insulating the cab and the second by reducing the engine noise components. The latter can be accomplished by using enclosures with high transmission loss, and with sound absorbent and panel damping materials.

In studying cab acoustics Priede (16) compared the in-cab noise spectrum when the vehicle was stationary at various engine speeds to that of the noise spectrum when the cab was physically disconnected from the vehicle's chassis. In the latter situation, loudspeakers were placed in the engine compartment to simulate engine noise. The playback of engine noise through the loudspeakers corresponded to engine speeds identically to the stationary vehicle.

Results indicated that up to 600 Hz, noise was airborne, while above 600 Hz the noise was structure borne. Noise in the high frequency region was attributed to vibration through the vehicle structure caused by gear meshing, exhaust mounting, transmission and the like.
CHAPTER IV

THEORY

The noise exposure of an operator can be evaluated relative to a particular regulation. It is expressed as a number, generally in percent, and is referred to as the noise dose, ND. The percent value would indicate the degree of noise exposure, therefore a percentage exceeding 100% would be termed as overexposed and would indicate an unsafe working environment in respect of the regulation.

The parameters of noise exposure in terms of its effects on the operator, are:

(a) the sound level in dBA

(b) the total time spent at each level within the range of the noise content of exposure.

Noise exposure can be determined by two methods, by means of an integrating noise dose meter or by calculations from the recorded noise data.

The calculation of noise dose in percent is given by the following general expression:

\[ ND = 100 \int_0^T \left[ \frac{P(t)}{0.632} \right]^n dt \tag{1-4} \]

where, \( P(t) \) is the A-weighted time varying sound pressure in Pa (pascals).

\( T \) is the measured duration in hours.

and, \( n \) is defined by the noise criterion or regulation in the measurement (for OSHA, \( n = 1.2 \); ISO, \( n = 2.0 \)).

The noise dose meter performs this calculation exactly within the accu-
T's accuracy of the instrument. Alternatively, the noise dose can be calculated from sample measurements by the following equation:

\[
ND = \left( \frac{C_1}{T_{1}^\prime} + \frac{C_2}{T_{2}^\prime} + \ldots \frac{C_n}{T_{n}^\prime} \right) \times 100\% \tag{2-4}
\]

where, \( C_n \) is the actual time (hrs) spent in the particular sound level.
\( T_n^\prime \) is the maximum permissible time (hrs) for the same particular sound level.
\( n = 1, 2, 3 \ldots \) (real)

The maximum permissible noise exposures for the ISO and the OSHA standards are represented graphically in Figure 2. These relationships can be expressed in mathematical terms, that is, allowable time in hours as a function of sound level in dBA. Such expressions are formulated in Appendix A and are summarized as follows:

(a) OSHA regulation (applicable for OSHA1A, OSHA1B and OSHA1C)
\[
\log(T^\prime) = 6.321 - 0.0602 (L_p) \tag{3-4}
\]

(b) POIR regulation
\[
\log(T^\prime) = 6.021 - 0.0602 (L_p) \tag{4-4}
\]

(c) ISO regulation
\[
\log(T^\prime) = 9.933 - 0.1003 (L_p) \tag{5-4}
\]

where, \( T' \) is the allowable time in hours and \( L_p \) is the sound level in dBA.

\( T_{1}^\prime, T_{2}^\prime \ldots T_{n}^\prime \) in Equation 2-4 can be determined by using one of the above equations for the required regulation.

Thus, it is possible to determine the noise exposure according to the existing hearing conversation criteria.
In this investigation the noise level was recorded continuously. This was processed by means of a sound level analyser, the Metrosonics dB-601 described in Chapter V.

The Metrosonics dB-601 provides the necessary data to compute \( C_n \), by providing the so-called \( P_1 \) scan. The \( P_1 \) scan represents the percent of time that the sound level is at a particular value. The range of measurement is covered in 1 dB steps. From the basic definition it is possible to compute the amount of time in hours or in minutes, for the total range of noise levels recorded in one dB steps.

\[
C_n = (P_1 \text{ scan})_n \times \text{total time}
\]

where, \( n \) is the subscript identifying the sound level in dBA.

For an eight hour work day the operators of transportation vehicles experience a combination of various modes of driving which have certain characteristics of noise levels experienced by the operator. Typically the modes are classified as city, highway and freeway driving.

Therefore, in determining the total noise dose for the different operating conditions it can be written that,

\[
\text{ND}_{\text{total}} = \left[ \text{ND}_{\text{city}} \right]_{T_1} + \left[ \text{ND}_{\text{highway}} \right]_{T_2} + \left[ \text{ND}_{\text{freeway}} \right]_{T_3}
\]

where, \( \text{ND}_{\text{total}} \) is the total noise dose percentage for the measured period of noise exposure.

\( \text{ND}_{\text{city}} \), \( \text{ND}_{\text{highway}} \), \( \text{ND}_{\text{freeway}} \) are noise dose percentages for the different modes of driving.

and, \( T_1, T_2, T_3 \) correspond to the actual time duration experienced for city, highway and freeway driving respectively.

Moreover, Equation 7-4 may be normalized to 8 hours representing a work-
where, \( ND_{8\text{hrs}} \) is the noise dose extrapolated to 8 hours.

\( T_{\text{total}} \) is the total time of measuring period and is the sum of

\( T_1, T_2, \) and \( T_3 \).

One of the objectives, as outlined in Chapter I, is to correlate the in-cab test results (either SAE J366a - Appendix H, or CSA Z107.23 Appendix G) with the equivalent noise levels for the three modes of driving conditions. The comparison of data between CSA Z107.23 and SAE J366a, discussed in Chapter IX, has shown close agreement with one another for each vehicle. SAE J366a is more complex to perform and requires a significantly larger test site than CSA Z107.23. For this reason CSA Z107.23 was chosen as one of the correlation parameters.

The noise dose could therefore be represented as a function of CSA Z107.23 to predict the total noise dose anticipated for the operator’s work day. Hence, the correlations are of the general form,

\[
ND = a \cdot (b \times \text{(CSA)})
\]

where, \( ND \) is the noise dose in percent

CSA is the CSA Z107.23 interior cab measurement in dBA.

\( a \) and \( b \) are constants obtained from linear regression analysis.

Therefore, \( a \) is the y-intercept and \( b \) is the linear slope.

For any particular payload haul, the total noise dose can then be expressed in a similar way, as shown in Equation 10-4,
\[ ND_{\text{total}} = \frac{T_1}{8} \left[ a + b \text{ (CSA)} \right]_{\text{city}} + \frac{T_1}{8} \left[ c + d \text{ (CSA)} \right]_{\text{highway}} + \frac{T_3}{8} \left[ e + f \text{ (CSA)} \right]_{\text{freeway}} \]

where, \( ND_{\text{total}} \) is the total noise dose over the measuring period of \((T_1 + T_2 + T_3)\).

"a", "b" and "c", "d" and "e", "f" are constants obtained from linear regression.

Thus, the predicted noise dose normalized to 8 hours is,

\[ ND_{\text{predicted 8 hrs}} = ND_{\text{total}} \times \frac{8 \text{ hrs}}{T_{\text{total}}} \]
CHAPTER V

INSTRUMENTATION

The particular instruments used in the acquisition of data and subsequent analysis are as follows:

5.1 Noise Level Monitoring System - "Ear Bug"

The noise recording system in Figure 3 is a portable unit which provides a means to record field data on cassette tape. It is particularly intended to measure noise exposure. This eliminates the use of heavy and complicated equipment which becomes impractical when constrained to a limited amount of space and other inconveniences. Once the data is stored on cassette tapes, a thorough analysis may be implemented in the laboratory.

The unit was originally developed by the Acoustic Division of the National Research Council of Canada and is made in a modified form at the University of Windsor. The earbug unit consists of three components, namely the subminiature microphone, the attenuator and tape recorder.

1. The subminiature microphone used is an electret film microphone model no. 1785 from Knowles Electronic Inc. The unit operates with a normal supply of 1.3 volts dc and 0.01 to 0.05 mA maximum. The output voltage signal varies from 0.2 to 0.9 volts dc with an impedance resistance of 4K ohms. Frequency response is flat from 3Hz to 8KHz. The electret film is enclosed in a metallic case with
overall dimensions of 2.28(L) x 5.59(W) x 9.49(H) mm. Three external contact terminals are provided on the case for power supply, common ground and output signal. The microphone is sufficiently small to be placed within the cavum of the concha in the external ear.

2. The attenuator circuit is a voltage divider which serves to provide impedance matching between the microphone and recorder, and as an attenuator for the recording system. The dynamic range of the recorder is determined by the choice of resistors in the circuit. Low and high range attenuators were used with corresponding dynamic ranges of 70 dBA to 100 dBA, and 85 dBA to 115 dBA.

3. The tape recorder is a Sony cassette recorder Model TC-55 which was modified to A-weighting characteristics specified by ANSI Standard SI.4-1971 of Type II tolerance. The recorder is powered by four "AA" batteries or by a dc adaptor which will operate on a 12.0 volt supply socket. The recorder weighs 850 grams with dimensions of 38(W) x 148(H) x 98(L) cm. The tape speed is 4.8 cm/sec (1 7/8 ips). The frequency response before modification ranged from 90 Hz to 10 KHz and after modification with miniature microphone and attenuator ranged from 200 Hz to 10 KHz Type II tolerance A-weighting. Frequency characteristic deviating from Type II tolerance may be corrected by using the Bruel and Kjaer one third octave spectrum shaper, moreover Type I tolerance was generally attained in this way. A calibration signal is recorded with the Bruel and Kjaer 4230 sound level calibrator which provides a 94 dB reference signal at 1000 Hz.
5.2 Brüel and Kjaer Type 4230 Sound Level Calibrator

The Brüel and Kjaer type 4230 is a portable unit (110mm long x 44mm in diameter) powered by a 9 volt battery. It provides an accurate calibration signal of 94 dB (re. 2x10^{-5}Pa) at 1000 Hz (±1.5%) within ±0.5 dB between 0°C to 50°C. The 1 KHz frequency is independent of the weighting network (A, B, C, and D). Standard adaptors are provided for the 1 inch and 1/2 inch diameters Brüel and Kjaer microphone. A special adaptor insert was made for the miniature microphone unit.

5.3 Brüel and Kjaer Type 4425 Noise Dose Meter, Modified Active Range 75-125 dBA

The Brüel and Kjaer Type 4425 is used in assessing industrial noise for hearing damage potential. The instrument is a portable unit and has dimensions 115mm (4.5in) long, 72mm (2.8in) width, 33mm (1.3in) thickness and is powered by two 9 volt batteries. Its battery life is 80 hours intermittent at 8 hours use per day on "ON" mode. A half inch condenser microphone Brüel and Kjaer Type 4125 cable and preamplifier ZE1032 can be directly "clipped" on the body of an operator.

The dosemeter Type 4425 conforms with ANSI S1.4-1971 Type S2A sound meter standard. The readout is obtained by means of pressing a button on the cover where up to four digit LED numbers are displayed. The dosemeter normally has a dynamic range of 90 dBA to 115 dBA with OSHA requirement including 10 dB crest factor allowance at 1 dB error. The dynamic range used in the survey was modified, 75 dBA to 115 dBA, anticipating low cab noise levels.

Calibration requires the use of a stopwatch and sound level
calibrator Type 4230 until the readout counts at a rate of 1 percent per second. An adjusting screw is provided to correct the rate of count.

5.4 Beat Frequency Oscillator Type 1022

Type 1022 is a precision signal generator and covers the frequency range from 20 Hz to 20 KHz. The frequency generated is sinusoidal. Output voltage is adjustable in 10 dB steps from 120 \( \mu \)volt to 12 volts and continuous within each 10 dB. The output signal automatically matches the impedance with the load. The power supply is 120 volts ac. The unit is designed for acoustical, vibrational and electrical uses.

5.5 Bruel and Kjaer Measuring Amplifier Type 2607

The measuring amplifier is a solid state, low noise, high gain measuring amplifier with an indicating meter. The unit requires a power source of 120 volts ac. Output response can be selected as, fast or slow or impulse measuring with maximum rms (root mean square) and peak-hold meter display. The unit conforms to IEC, ANSI and DIN Recommendations. Output range for attenuation is 0 to 150 dB and amplification range 0 to 20 dB in 10 dB steps with accuracy within \( \pm 0.1 \)dB. Interchangeable scales are provided for voltage, acceleration and sound level measurements. Weighting networks A, B, C, and D are provided within 2 Hz to 200 KHz. Upper and lower audio frequency range can be limited from 22.4 Hz to 22.4 KHz. An internal calibration signal for the unit supplies 50 mvolt at 100 Hz for calibration.
5.6 **Bruel and Kjaer Type 4145 1 Inch Microphone**

The Bruel and Kjaer Type 4145 1 inch microphone is a freefield condenser microphone which outputs a voltage proportional to the sound pressure level. It has a frequency response from 2 Hz ± 0.5 Hz (-3 dB) to 18 KHz (±1.5 dB) for free field 0° incidence. The dynamic range (ref. $2 \times 10^{-5} \text{N/m}^2$) has an upper limit (4%) distortion 144 dB with a lower limit determined by the noise of the amplifier.

5.7 **Bruel and Kjaer Type 2307 Level Recorder**

The level recorder provides the means to accurately record signal levels in the frequency range from 2 Hz to 200 KHz with AC or DC modulation. The recording unit can be selected to write at 15 different writing speeds and 5 selectable lower limiting frequencies. The dynamic range is dependent on the available potentiometer ranges provided with the instrument. The unit requires a power supply of 120 volts ac.

5.8 **Metrosonics dB-601 Sound Level Analyser**

The "Metrosonics" is used with the personal noise level monitoring system. The analyser is contained in a weatherproof aluminum case and utilizes a rechargeable sealed lead acid battery. It has an automatic charging circuit to operate either on 12 V dc or 120 V ac power source.

The analyser operates with a memory consisting of over 100 storage registers each 1 dB wide and with a capacity to retain over 65,000 samples per register, totaling 6.5 million samples. In order to avoid
overflow a guide is provided to select the sample rate and a recommended analysis time before reaching a memory overflow. Increasing the sample rate provides a finer resolution while long sampling rates permit an extended time of usage.

The unit provides an internal microprocessor that enables computation of the following:

(a) \( L_{\text{eq}} \) - equivalent noise level using the equal energy concept.

\[
L_{\text{eq}} = 10 \log_{10} \frac{1}{N} \sum_{i=1}^{N} \frac{L_i}{10}
\]

where, \( N \) is the number of samples.

\( L_i \) is the sound level in each sample.

\( i = 1, 2, 3 \ldots N \) (real)

(b) Interfacing with an X-Y plotter the \( P_1 \) scan is plotted.

\( P_1 \) scan relates the percent of time that the sound pressure level is at each level, starting from the lowest amplitude and continuing in 1 dB steps to the highest level. Digital readouts may also be obtained from the analyser.

(c) Another plot is obtained with the X-Y plotter namely the \( L_n \) scan, enabling all 100 values to be plotted starting from \( L_{99} \) to \( L_0 \). \( L_n \) scan represents a cumulative distribution.

This is usually a plot of percentile level (Z) on the vertical axis and sound pressure level on the abscissa. Hence each value \( L_n \) shows the level exceeding \( n \) percent of time during a sample period. The \( L_n \) scan can be manually selected, this can be achieved by selecting an \( n \) value on a tunable dial and the corresponding dB value is displayed on the instrument.
Input circuitry is provided for microphones of 1/2 inch and 1 inch diameters with sensitivity between between -25 dB and -40 dB (re. 1 V/Pa) and with a dynamic range from 20 dB to 120 dB. A-weighting is automatically provided with a microphone input. Input signals from tape recorders are not A-weighted and hence must be modified for A-weighting. Dynamic range is from -8 dB to +19 dB from the indicated switch position. Averaging response fast or slow rate is defined by ANSI S1.4-1974 Type I.

5.9 **Bruel and Kjaer Impulse Precision Sound Level Meter Type 2209**

The precision sound level meter is a portable instrument which has applications to measure both noise and vibration. The instrument fulfills the requirement of IEC 179 and DIN 45633 parts 1 and 2 for precision sound level meters. The instrument is powered by three standard 1.5 volt batteries (size D) giving up to 10 hours of continuous operation. There are four weighting networks "D", "A", "B", and "C".

The frequency range with a one inch Bruel and Kjaer microphone Type 4145 is 10 Hz to 18 KHz (±2 dB). The meter scale is graduated in dB from -10 to +10 dB with a square law rectifier for signals with crest factors up to 3. The instrument's operating temperature range is -10°C to 60°C (14°F to 140°F). It has dimensions of 31(L) x 9(W) x 12(H) cm.

5.10 **Bruel and Kjaer Filter Set Type 1613**

The octave filter set is a portable unit which has dimensions 15.5(L) x 22(H) x 9.0 (W) cm. The filter set is compatible with the impulse precision level meter Type 2209. There are eleven octave filters
with center frequencies arranged from 31.5 Hz to 31.5 KHz in accordance with ISO Standard. Each filter satisfies the requirement IEC Recommendation 225 and ANSI S1.11 Class II. The signal from each filter may be individually calibrated from 0 to 50 dB attenuated by screwdriver adjustments.

5.11 Hewlett Packard 7045A X-Y Recorder

The HP recorder is used to plot cartesian coordinate graphs from dc electrical information. The unit is portable and has dimensions of 400(l) x 456(h) x 165(w) cm. The 7045A instrument features high speed capacity and rapid acceleration to accurately record high frequency and fast moving input signals. The recorder includes 10 calibrated dc input ranges in each axis from 0.5mV/in (0.20 mV/cm) to 10 V/in (4 V/cm). Accuracy is ±0.17 of full scale. The required input power is 115 volts ±10% and 50-4000 Hz range.
CHAPTER VI

UNCERTAINTY ANALYSIS

6.0 INTRODUCTION

In any measuring system there are inherent uncertainties which are associated with the instrument inaccuracies and with the technique of measurements. Instrument errors are a combination of linearity, hysteresis, repeatability and calibration inaccuracies. The technique of measurement is critical since there may be more than one parameter being measured at that point.

Hence, in effect, both the instrument and measurement technique errors result in a system's uncertainty. This chapter discusses the uncertainty in the calculated parameters.

6.1 Uncertainty Due to Body Baffling and Cab Acoustics

It is evident in a previous study (21) that body baffling effects will either attenuate or amplify noise levels. The same study indicates that the shape of the person, the type of clothing and the person's posture will influence the noise readings.

For this survey an added parameter to consider is the interior cab construction of buses and heavy trucks which have varying acoustical characteristics. Standing waves in vehicular cabs would no doubt contribute to the overall noise reading. Frequency real time analysis reveal that the noise consist of pure tone (especially at high
speeds and window open), the body baffling parameter could under some conditions have measurable influence. As the vehicle speed varies, the spectral content of noise changes and so will the spatial distribution of noise within the cab.

However, since both body baffling and cab acoustic are part of the noise environment, these parameters do not contribute errors in the measured noise exposure recordings conducted in vehicles.

6.2 Uncertainty in Calculating the Noise Dose (ND)

The governing equation for noise dose is,

\[ \text{ND} = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n} \right) \times 100 \]  \hspace{1cm} \text{1-6}

where, \( C_n \) is the amount of time spent in the \( n \)th sound level.

\( T_n \) is the allowable time in the \( n \)th sound level.

\( n = 1, 2, 3 \cdots m \) (real)

Hence the uncertainty in ND is,

\[ \omega_{\text{ND}} = \left[ \left( \frac{\partial \text{ND}}{\partial C_1} \times \omega_{C_1} \right)^2 + \left( \frac{\partial \text{ND}}{\partial C_2} \times \omega_{C_2} \right)^2 + \cdots + \left( \frac{\partial \text{ND}}{\partial C_n} \times \omega_{C_n} \right)^2 \right]^{0.5} \] \hspace{1cm} \text{2-6}

where, \( \omega_{C_n} \) is the uncertainty of the \( n \)th time (in the \( n \)th sound level) in minutes.

\[ \omega_{C_1} = \omega_{C_2} = \cdots = \omega_{C_n} = 1 \text{ minute (estimated)} \]

thus,

\[ \frac{\omega_{\text{ND}}}{\text{ND}} = \left[ \left( \frac{\omega_{T_1}}{T_1} \right)^2 + \left( \frac{\omega_{T_2}}{T_2} \right)^2 + \cdots + \left( \frac{\omega_{T_n}}{T_n} \right)^2 \right]^{0.5} \times 100 \]  \hspace{1cm} \text{3-6}

where, \( \frac{\omega_{\text{ND}}}{\text{ND}} \) is the error in ND.
simplifying,
\[ \frac{w_{\text{ND}}}{\text{ND}} = \left[ \left( \frac{1}{T_1} \right)^2 + \left( \frac{1}{T_2} \right)^2 + \cdots + \left( \frac{1}{T_n} \right)^2 \right]^{0.5} \times 100\% \]  
4-6

For a typical analysis with a noise level range from 75 dBA to 105 dBA,
\[ \frac{w_{\text{ND}}}{\text{ND}} = \left[ \left( \frac{1}{64} \right)^2 + \left( \frac{1}{32} \right)^2 + \left( \frac{1}{16} \right)^2 + \left( \frac{1}{8} \right)^2 + \left( \frac{1}{4} \right)^2 + \left( \frac{1}{2} \right)^2 + \left( \frac{1}{1} \right)^2 \right]^{0.5} \times 100\% \]  
5-6

and, \( T \) is the allowable time (in this case according to the OSHA standard) expressed in minutes.

hence, \( \frac{w_{\text{ND}}}{\text{ND}} \ll 1\% \).

6.3 Uncertainty in Computing \( L_{\text{eq}} \)

The Metrosonic dB-601 Sound Level Analyser is programmed to compute the \( L_{\text{eq}} \) from the tape recordings. The internal microprocessor has a resolution of 1 dB, and has an accuracy of \( \pm 0.5 \) dB, hence the maximum uncertainty of the instrument is 1 dB.

6.4 System Measurement Error

The system measurement errors comprise of the input error at the measuring station and a combination or superposition of the "associated equipments" error (such as microphone and tape recorder, and electronic noise level analyser system) to determine the magnitude of the measured parameter.

The error is obtained by computing the square root of the sum of the squares expressed in the following equation:
\[ E_S = \left[ \sum_{x=1}^{n} E_x^2 \right]^{0.5} \]

where, \( E_S \) is the system's error.

\( E_x \) is the errors of the "associated equipment" to determine the magnitude of the measured parameter.

\( x = 1, 2, 3 \ldots n \) (real)

expanding Equation 6-6,

\[ E_S = \left[ E_I^2 + E_{MT}^2 + E_A^2 + E_B^2 \right]^{0.5} \]

where, \( E_I \) is microphone location error.

\( E_{MT} \) is the combined microphone and tape recorder error.

\( E_A \) is the Metrosonic dB-601 analyser system

\( E_B \) is the body baffling error

\( E_S \) is the measuring error

Studies (21, 22, 23) on the "earbug" system have indicated \( E_I = 0.5 \) dBA and \( E_B = 2 \) dBA. The combined microphone and tape recorder error, \( E_{MT} = 0.5 \) dBA Type II tolerance (22) and the Metrosonic dB-601, \( E_A = 1 \) dBA as per specification.

\[ E_S = \left[ 0.5^2 + 0.5^2 + 1^2 + 2^2 \right]^{0.5} \]

\[ = 2.3 \text{ dBA} \]

6.5. Uncertainty in the Predicted Noise Dose (Criterion OSHA1C)

The results of the predicted noise dose are compared to the measured results taken with the earbug unit. The earbug's recorded data were processed through the Metrosonic dB-601 to convert these measurements
to noise dose results. The actual measured result is considered to have minimum error compared to the predicted noise dose. The predicted noise dose results are given in Equations 18-9 and 19-9 in Chapter IX. These correlated equations predict statistically the probable noise dose exposed to the operators.

The uncertainty of the predicted noise dose is presented by

\[
\sigma_{\text{predicted estimate}}^2 = \frac{\sum_{x=1}^{n} (Y_{1} - Y_{1}')^2}{n-2}
\]

where, \(\sigma_{\text{predicted estimate}}^2\) is the variance of the predicted values estimated by the regression line.

\(Y_{1}\) is the measured noise dose in percent.

\(Y_{1}'\) is the predicted noise dose in percent.

\(i = 1, 2, 3 \ldots n\) (real)

The preceding equation denotes the error of the estimate as the standard deviation of obtained values around the regression line. This is equivalent to say that the error is indicated by the difference between predicted and observed values. In computing the error of the predicted values from Tables 11.0 and 12.0 the following values are obtained respectfully,
\( \sigma_{\text{predicted estimate}} = 35 \) (noise dose)
right ear (8 hours)

\( \sigma_{\text{predicted estimate}} = 71 \) (noise dose)
left ear (8 hours)
CHAPTER VII

EXPERIMENTAL PROCEDURE

7.0 Introduction

The survey was made possible through the co-operation of several Windsor (Ontario) based transportation companies, where arrangements were made to provide in-service trucks to monitor the operator's noise exposure during his normal work day and normal payload runs.

The companies that participated are the following:

(a) International Cartage Limited
(b) Kingsway Transportation Limited
(c) Allied Chemical Limited
(d) Bondy Cartage Limited
(e) Transit Windsor
(f) Essex Transportation Company
(g) Kovinsky and Sons Limited

The numbers of samples to date total 66 motor vehicles which consist of a variety of classifications, these include (a) city public diesel buses (b) urban school buses (c) heavy trucks over 30,000 lb. GVW (gross vehicle weight), namely tandem-rear axle tractor trailers (shown in Figures 4 and 5) and dump trucks.

7.1 Tractor Trailers and Heavy Trucks

The methodology used in the measurement required a qualified
technician to monitor the operator's noise exposure during his normal work day. The measuring system consisted of three ear bug units. One microphone was placed in each of the left and right ears of the operator. The remaining microphone was suspended six inches (15 cm) from the right ear (inner side of cab) at ear level as shown in Figures 6 and 7. Hence all measurements were taken at ear level. It should be noted that the microphones clipped to the operator's ears are positioned within the cavity of the concha but away from the entrance to the ear canal. In this position, as shown by previous investigations, the measurements is least affected by external variables and it is almost proportional to the sound pressures at the ear (21).

The cassette recorders were powered by 9 volt car adaptors which were connected to the vehicle's fuse panel as shown in Figure 8. The units were placed in protective padded containers to minimize shock and vibrations during the measuring period as shown in Figure 9. Under certain operating conditions, such as in dump trucks, operators required frequent "stepping in and out" from the cab. In this case the instrumentations were strapped on the operator; see Figure 10.

Once the instruments were arranged, precautions were taken so that the dangling wires did not interfere with normal functions of the operator of the vehicle. This was readily done by means of taping the array of wires onto the cab walls.

For comparison of noise exposure calculations from the "ear-bug" results, a commercial dosimeter was used. This was the portable Bruel and Kjaer Type 4425, with its integration characteristic set to 90 dBA continuous noise for 8 hours equal 100% exposure. The particular dosimeter had a cut-off band limit of 75 to 115 dBA range. Calibration
of the dosimeter was checked frequently using a Bruel and Kjaer 4230 calibrator.

All instruments were calibrated using the Bruel and Kjaer Type 4230 calibrator with an insert molding especially designed for the miniature microphone. The calibration signal was recorded before and after each hour or per side of the cassette tape. Plug-in attenuators were used in conjunction with the recording system for different dynamic ranges. A low range attenuator for 70 to 110 dBA and a high range attenuator for 80 to 115 dBA dynamic range. The choice was dependent on the noise level within the cab, which was measured with the Bruel and Kjaer Type 2209 precision sound level meter. The apriori measurement was rather important for high noise level recordings, especially when the operator used a citizen band radio (CB).

Noise levels at the three designated locations, mentioned previously, were recorded simultaneously during the "on" period, and for each period dosimeter readings were noted. The "on" time is defined as the vehicle idling or running and the operator seated before the steering wheel. During a typical run, say from Windsor-Toronto-Windsor, which may take up to 16 hours, a log describing the trip was documented. The information included weather conditions, the type of driving, vehicle specifications, equipment used, vehicle speed and the like. The actual "on" time for such a trip may total up to 10 hours of recordings.

Two interior noise tests were also conducted. One of the test was the stationary CSA 2107.23 and the other the pass-by SAE J366a interior measurement. These standard procedures are described in Appendix G and H. This required the use of the Bruel and Kjaer Type 2201 precision sound level meter with a one inch microphone and a Bruel and Kjaer
Type 1613 octave analyser. Various views of the CSA set up are shown in Figures 11 and 12.

7.2 Public City Buses

Most public city buses are diesel powered vehicles which have their engine located in the rear. In the measuring procedure used, a qualified technician was seated at the back of the vehicle. He was equipped with an ear bug unit and a dosimeter. The microphones worn by the technician were located on the most inner side of the vehicle (towards the center of the vehicle). Continuous recordings were obtained for a typical work day.

7.3 Country School Buses

Typical country school buses were powered by gasoline engines which are located in the front of the vehicle. The ear-bug and dosimeter equipment were worn by the driver during the total "on" time while the continuous noise was recorded. The ear-bug and dosemeter microphones were located on the right ear and right lapel respectively.
CHAPTER VIII

ANALYSIS OF DATA

8.0 Introduction

This section details the analysis of data from the recorded tapes.

8.1 Analysis Procedure

The preliminary preparations to the analysis required a playback on the Brueel and Kjaer Type 2307 graphic level recorder which yielded a strip chart of noise level versus time for each particular vehicle. Thus, for each vehicle there were three recordings corresponding to the various microphone positions, namely left ear, right ear and 6-inches from the right ear. From this time history and from the corresponding log of events, designated portions on the chart were identified according to the modes of driving, such as city, highway and freeway. Occurrences of malfunctions due to intermittent recording, battery failure, or faulty cassette tapes were noted so that these tape segments could be omitted from the analysis.

The tape recordings for the three microphone positions were then analysed with the Metrosound dB-601 and Brueel and Kjaer 2307 level recorders. For each microphone position a detailed analysis was conducted for each of the three modes of driving. The data were always played back at the same speed and on the same unit recorder. Its output was corrected
by means of the Brue and Kjaer equalizer for A-weighting Type I
tolerance. Calibration signals were provided at the beginning and end
of each cassette recording side.

For a particular vehicle all accumulated city modes were
analysed on the Metrosonics dB-601, where the sample frequency is dependent
on the total length of time (in this case city driving), which was then
selected for maximum sample rate. Data reduction provided by the
Metrosonics dB-601 include $L_0$ to $L_{99}$ scan, $P_1$ scan, total time (hours)
and $L_{eq}$ (dBA). For $L_n$ scan and $P_1$ scan, representing sound level versus
percent, both a plot as well as the numerical (digital) outputs were
recorded. This was then repeated for highway and freeway modes for each
microphone position. Typical narrow band frequency analysis samples
were then taken for each driving mode and microphone position. The
arrangement of instruments for the analysis is shown in Figure 13.

The $P_1$ scan digital output was further analysed in calculating
the noise dose in accordance with the various criteria listed below:

(a) $OSHA_{1A}$, 90 dBA = 100% for 8 hours, range 90 to 115 dBA,
    $q = 5$
(b) $OSHA_{1B}$, 90 dBA = 100% for 8 hours, range 85 to 115 dBA,
    $q = 5$
(c) $OSHA_{1C}$, 90 dBA = 100% for 8 hours, range 75 to 115 dBA,
    $q = 5$
(d) $POIR$, 85 dBA = 100% for 8 hours, no cut-off, $q = 5$
(e) $ISO$, 90 dBA = 100% for 8 hours, range 80 to 130 dBA,
    $q = 3$

The above were calculated for each driving mode and microphone position.

Certain correlations were then computed using linear regression
analysis for various relationships including:

(a) CSA Z107.23 Test versus Noise Dose re. OSHA A
(b) CSA Z107.23 Test versus Noise Dose re. OSHA B
(c) CSA Z107.23 Test versus Noise Dose re. POIR
(d) CSA Z107.23 Test versus Noise Dose re. ISO R1999
(e) $L_{eq}$ (right ear) versus $L_{eq}$ (left ear)
(f) $L_{eq}$ (right ear) versus $L_{eq}$ (6 inches from right ear)

These relationships were used to determine the predicted noise dose of in-cab truck noise based on CSA Z107.23 stationary test. The computation of the many calculations incorporated the use of the IBM 360 computer system.
CHAPTER IX

DISCUSSION OF RESULTS

9.0 Introduction

The results of the in-cab exposure study for the various transportation vehicles are presented and discussed in this chapter. The duration of data recordings has exceeded 500 hours. The various types of vehicles used in the study are a representative cross-section of in-service transportation vehicles.

During the "in-cab" noise measurement investigation a total of 8 buses and 58 heavy diesel transportation vehicles were surveyed. Tables 1.0 and 2.0 indicate the type and specifications of these vehicles. The survey was made possible through the cooperation of local transportation companies and their drivers in Windsor, Ontario. The choice of vehicles was dependent on the availability of these vehicles at the time of request. The results for these vehicles are presented in Tables 3.0 through 5.0 inclusive. Many of the vehicles were relatively new and well maintained.

9.1 Standard Measuring Procedure

Interior standard measurements were conducted for the majority of vehicles. The particular procedures undertaken during the operators' normal work day included the CSA Z107.23 and SAE J366a evaluation.

The SAE J366a procedure required a special and relatively
large test site. It was also relatively complex, time consuming and required the recording of 1-octave unweighted bands during the acceleration of the vehicle in a selected gear ratio. The CSA Z107.23 interior cab evaluation was in comparison a much simpler and quicker procedure.

The results are presented in Tables 3.0 through 5.0. They indicate that the values obtained with the CSA Z107.23 and the SAE J366a standard procedures are within 2 dB. Differences in reading are believed to be predominantly due to the different microphone positions. In view of the closeness of these results it was decided to use the simpler CSA procedure as the basis of the prediction method to be developed.

9.2 Buses

Results for both school and public transit buses are presented in Tables 2.0 and 3.0. Vehicles A through G were school buses while vehicle H was the only public transit bus surveyed.

Equivalent noise levels during a normal work day for buses in general are within present hearing protection regulations such as ISO R1999 and OSHA.

Figure 15 shows the noise generated in a school bus and monitored at the drivers' right ear. The trace indicates the many peaks attributed to loud conversation and screams produced by students, superimposed on the engine noise. It would appear that passenger noise predominately contributes to the high levels perceived by the driver.
The "stop and go" of the bus is not as periodic as that of the city bus shown in Figure 14. School bus drivers indicated that passenger noise levels predominate and can reach very high values.

The public transit bus results, shown in Figure 14 and recorded in the rear of the vehicle, indicate a constant pattern of characteristic city driving. The "stop and go" driving is typical of public transit vehicles and constant speed conditions exist only for short periods. The peak noise levels in Figure 14 are attributed to gear changes and vehicle acceleration.

9.3 Trucks

Tables 1.0 and 2.0 indicate the specifications of the 58 commercial vehicles surveyed. The results of noise exposure measurements obtained on these vehicles are presented in Tables 3.0 through 5.0 inclusive.

Noise experienced by drivers consists of many frequency components, which characterize the working environment within the cab. The complex frequency spectrum is comprised of individual sources produced by the engine, road excitation and aerodynamic noises. Typical spectra of noise, for different monitoring positions inside the cab environment and for corresponding modes of driving, are presented in Figure 17 through 20. These spectra are for the same vehicle and at approximately the same instant of time as recorded on tape. From the general shape of the spectrum it is apparent that predominant components are in the lower frequency range namely, 0 to 3000 Hz, and that the sound level decreases with increase in frequency. The left ear position shows no
Table 4.0 summarizes the equivalent sound levels for heavy trucks at the particular monitoring position with the corresponding driving modes. Results indicate that freeway driving produced higher noise levels than city or highway driving. Also, the left ear is subject to higher noise levels than the right ear or the center of cab positions, for the majority of driving modes. This was also evident from the frequency spectra.

The distribution of time spent, expressed in each sound level, is shown for the right ear in Figures 21, 22 and 23. This distribution is similar for the left ear and center cab position.

The city driving curves, shown in Figures 21 and 22 indicate a skewed distribution of lower levels in comparison with highway and freeway modes. City driving usually consists of engine idling when the vehicle is stationary and accelerating periods when approaching stop signs. Increased noise levels are experienced when the vehicle accelerates from a standstill position or maintains speeds for short intervals. Highway and freeway recordings show an absence of the low noise distribution since the vehicle operates continuously at high engine rpm (revolutions per minute) and speeds up to 100 kph (60 mph). This is indicative of the amount of time spent in higher noise levels. The significance of these distributions relates the influence of the cut-off ranges in calculating the noise dose.

A dosimeter with a lower cut-off frequency of 90 dBA or even 85 dBA would provide a completely unrealistic exposure reading. It is clearly evident that the noise exposure is highest in freeway driving, which is followed in decreasing order by highway and city driving.

Tables 5.0 through 8.0 are the calculated values of the noise dose based on five different exposure regulations, namely OSHA1A, OSHA1B,
OSHA1C, POIR and ISO R1999. The results provide a survey of current regulations (OSHA1A and ISO R1999) as well as proposed and pending regulations (OSHA1B, OSHA1C and POIR). Results in Tables 5.0 indicate according to OSHA1A that 13% of the vehicles have in-cab noise levels exceeding the safety limit; in Table 6.0 according to OSHA1B that 20% of the vehicles exceed the in-cab safety limit; and in Table 7.0 according to OSHA1C that 24% vehicles have in-cab noise levels exceeding the safety limit. The percentages are based on results with respect to right ear monitoring position.

In Table 8.0 the results for ISO R1999 are shown. This is more stringent than the preceding regulations and therefore noise dose calculations result in higher exposure values. Approximately 33% of the surveyed vehicles indicate overexposure with respect to right ear monitoring position.

POIR is considered the most stringent in noise exposure evaluation since the allowable time in any sound level has been greatly reduced. The obtained results indicate that at least 90% of the vehicles have a hazardous working environment based on measurements at the right ear monitoring position. Since even this regulation is not considered to give complete protection from the hearing loss hazard the inadequacy of the preceding regulations is effectively emphasized.

In each case the overexposure is significantly increased by a working day longer than 8 hours and by the use of CB radio or even a normal radio.

CB radio increases the overall noise level significantly. Results in Table 10.0 compare noise level locations with and without CB radio. It is indicated that the overall noise level can increase up
to 6 dBA. The inner ear and center cab locations register a larger increase compared to the right ear position. This is justified since CB radios are usually placed in the center of the cab either beside the driver or on the window dash panel.

The data presented in Tables 4.0 through 9.0 were correlated for the various relationships indicated previously in Chapter VII and are presented in Figures 24 through 40 for the various microphone positions and modes of driving.

Figures 24 to 28 show the correlation of $L_{eq}$ right ear versus $L_{eq}$ left ear, and $L_{eq}$ right ear versus $L_{eq}$ center of cab for city, highway and freeway modes of driving. On the average the value of $L_{eq}$ at the right ear was approximately 2 dBA higher than at the center of cab and at the left ear over 1 dBA higher than at the right ear. The overall noise was highest during freeway, followed in descending order by highway and city driving.

Figures 29 to 37 show various correlations between CSA Z107.2-23 standard procedure and noise dose exposure standards POIR, OSHA 1910.95 and ISO R1999. The results are also presented in Tables 4 through 9.

OSHA standard is currently used in North America however this does not offer adequate hearing protection and it is likely that POIR regulation may be adapted. ISO R1999 may also be a possible alternative.

The most obvious result is that noise exposure of the operator is high in freeway driving. The hearing damage risk in
this case is further increased by the durations of freeway hauls, which generally exceed eight hours. It is also evident that the highest noise level occurs at the left ear which is closest to the open window.

The correlation equations CSA Z107.23 versus OSHA LC in Figures 29 to 31 form the basis of the prediction equations. The list of all the correlated equations are summarized in Appendix F for convenience.

Combining Equations 1-F, 2-F and 3-F in Appendix F the following equations are formed to predict the noise dose at the right ear:

\[ \frac{ND_{OSHA_LC}}{right\ ear} = \frac{T_{city}}{8} \times \left[ 11.63 \times (CSA) - 931.74 \right] + \]

\[ \frac{T_{highway}}{8} \times \left[ 10.99 \times (CSA) - 864.07 \right] + \]

\[ \frac{T_{freeway}}{8} \times \left[ 16.4 \times (CSA) - 1304.75 \right] \]

It is noted that the predicted noise dose is a function of time in hours and CSA stationary test Z107.23 in dBA.

Similarly based on the results from Equations 4-F, 5-F and 6-F the prediction equations for the left ear is:
\[ \text{NDOSHALC left ear} = \frac{T_{\text{city}}}{8} \times \left[ 9.71 \times (\text{CSA}) - 765.34 \right] + \]
\[ \frac{T_{\text{highway}}}{8} \times \left[ 13.16 \times (\text{CSA}) - 1038.42 \right] + \]
\[ \frac{T_{\text{freeway}}}{8} \times \left[ 37.04 \times (\text{CSA}) - 3068.89 \right] \]

The procedure for the right ear should be used since the hearing loss is evaluated for the ear with the lesser damage. Tables 11.0 and 12.0 are the comparisons of noise dose results and predictions for the particular vehicles normalized to an eight hour work period. These results were based on the combination of driving modes (city, highway, and freeway) representing a regular work day. The predicted results are functions of the correlated data shown in Figures 38 through 40 inclusive.

Results of the right ear predictions are presented in Table 11.0 with the corresponding graph in Figure 39. The measured results and the predicted results show a correlation factor of \( r = 0.45 \). The standard deviation in the predicted noise dose result is 35\% which corresponds to a standard deviation in an equivalent noise level of 2 dBA.

The left ear position is also analyzed in the same manner, these results are tabulated in Table 12.0 and also presented in Figure 40 with a corresponding correlation factor of \( r = 0.56 \). The standard deviation in the predicted noise dose result is 71\% interpreted as a standard deviation in the predicted equivalent noise level.
of 3 dBA.

The difference between the predicted and measured noise doses is approximately of the same magnitude as the range of error for the commercial noise dose meter. Thus, the prediction method is an acceptable alternative to the use of the noise dose meters and is significantly cheaper and simpler to use.

Table 13.0 and Figure 38 is the comparison of the predicted noise dose for the right ear and the measured noise dose with the dose meter located at the right lapel position. Results show a similar standard deviation of 2 dBA in the predicted noise level.
CONCLUSIONS

The following conclusions can be drawn:

(i) The maximum in-cab sound levels measured by means of the standard procedures (SAE J366a and CSA Z107.23) are within 2 dB of each other. The difference is within the measuring error accepted in these procedures which suggests that both are equally acceptable. The CSA Z107.23 test procedure is a preferred choice owing to the relative simplicity of procedure and test site requirements.

(ii) The highest noise exposure exist during freeway driving followed in descending order by highway and city driving.

(iii) The measured noise level increases in the order: center of cab, right ear and left ear. The average difference between center of cab and left ear is 6 dBA and between right ear and left ear it is 3 dBA. Most standard measuring methods use approximately the center of cab position for measurements. Since the average difference between this location and the left ear is 6 dBA, serious under estimates of the operator exposure may result from using such a standard procedure.

(iv) Noise dose calculations based on ISO R1999, OSHAIA, and OSHAIB indicate that approximately 30% of the tested
diesel trucks offer the potential of exceeding the permissible exposure limits during freeway driving. This figure is further increased for hauls exceeding 8 hours daily duration.

(v) Results based on the POIR regulation indicate that for the combination of city, highway and freeway driving where freeway driving mode predominates, 90% of the in-service diesel trucks are considered to have unacceptable noise levels.

(vi) City buses and school bus operators are subjected to lower noise levels and a hearing loss hazard is unlikely to exist.

(vii) The continuous use of a CB radio inside the cab during the normal work period will result in a 3 to 6 dBA increase in noise level compared to non-users of CB radio.

(viii) Correlation with the predicted results shows an overall standard deviation of 35% in the predicted noise dose which corresponds to a standard deviation of 2 dBA in the equivalent noise level. Thus the prediction method gives results which compare very favorably with those obtained using commercial noise dosimeters. Because of its relative simplicity of application and significantly lower cost, the prediction method is eminently suitable for practical applications.
LIST OF REFERENCES


PERSONAL NOISE LEVEL MONITORING SYSTEM

FIGURE 3
OPERATOR WITH INSTRUMENTATION

FIGURE 6

CLOSE UP OF MINIATURE EAR MICROPHONE

FIGURE 7
POWER SOURCE CONNECTED TO FUSE PANEL

FIGURE 8

MONITORING INSTRUMENTATION

FIGURE 9
OPERATOR STRAPPED WITH INSTRUMENTATION

FIGURE 10
Writing Speed: 31.5 mm/s
Paper Speed: 0.1 mm/s
Microphone in right ear of passenger

FIGURE 14 Vehicle #6; City Bus on Urban Run
FIGURE 15 Vehicle #2; School Bus on Highway Run

Writing Speed: 31.5 mm/s  Paper Speed: 0.1 mm/s  Microphone in right ear of driver
FIGURE 17  FREQUENCY ANALYSIS OF FREEWAY DRIVING MONITORED RIGHT (HIS/EP) EAR
FIGURE 22 STATISTICAL DISTRIBUTION FOR CITY DRIVING
FIGURE 21  STATISTICAL DISTRIBUTION FOR VARIOUS DRIVING CONDITIONS
FIGURE 22  STATISTICAL DISTRIBUTION FOR CITY DRIVING
FIGURE 23 STATISTICAL DISTRIBUTION FOR FREEWAY DRIVING
$L_{eq} \text{ (RIGHT EAR)} = 0.830 \ L_{eq} \text{ (CAB)} + 16.05$

$r = 0.91$

$\sigma_y = 2.75 \text{ dBA}$

$\sigma_x = 3.00 \text{ dBA}$

Figure 24 $L_{eq}$ (RIGHT EAR) VERSUS $L_{eq}$ (CAB) - HIGHWAY
\[ L_{eq} \text{ (RIGHT EAR)} = 0.722 \ L_{eq} \text{ (CAB)} + 25.99 \]

\[ r = 0.76 \]

\[ \sigma_y = 2.29 \]

\[ \sigma_x = 2.40 \]

FIGURE 25  \( L_{eq} \text{ (RIGHT EAR)} \) VERSUS \( L_{eq} \text{ (CAB)} \) - FREEWAY
$L_{eq\ (RIGHT\ EAR)} = 0.910 \ L_{eq\ (CAB)} + 8.82$

$r = 0.94$

$\sigma_y = 3.08 \text{ dBA}$

$\sigma_x = 3.19 \text{ dBA}$
$L_{eq \text{ (RIGHT EAR)}} = 0.968 \times L_{eq \text{ (LEFT EAR)}} + 1.58$

$r = 0.88$

$\sigma_y = 3.06 \text{ dBA}$

$\sigma_x = 2.79 \text{ dBA}$

**Figure 27** $L_{E0 \text{ (RIGHT EAR)}}$ versus $L_{E0 \text{ (LEFT EAR)}}$ - Highway
Figure 28. \( L_{eq} \) (right ear) vs. \( L_{eq} \) (left ear) - freeway.

\[ \text{LEq (right ear)} = 0.58 \times \text{LEq (left ear)} + 35.80 \]

\[ r = 0.76 \]

\[ \sigma_y = 2.02 \text{ dBA} \]

\[ \sigma_x = 2.66 \text{ dBA} \]
\[ N_{\text{OSHA1C}} = 10.99 \ (\text{CSA}) - 864.07 \]
\[ r = 0.77 \]
\[ \sigma_y = 28.31\% \]
\[ \sigma_x = 3.35 \text{ dBA} \]

**Figure 30** OSHA\(^{1}\)C (Right Ear) versus CSA-Highway
\[ N_{\text{OSHAIC}} = 16.4 \text{ (CSA)} = 1304.75 \]

\[ r = 0.69 \]

\[ \sigma_y = 33.27\% \]

\[ \sigma_x = 2.95 \text{ dBA} \]

**Figure 31**: OSHAIC (Right Ear) Versus CSA-Freeway.
\[ ND_{ISO} = 16.13 \text{ (CSA) } - 1321.29 \]
\[ r = 0.65 \]
\[ \sigma_y = 33.86\% \]
\[ \sigma_x = 3.22 \text{ dBA} \]

FIGURE 32 ISO (RIGHT EAR) VERSUS CSA-CITY
\[ N_{ISO} = 17.54 \text{ (CSA)} - 1427.37 \]

\[ r = 0.75 \]

\[ \sigma_y = 44.20\% \]

\[ \sigma_x = 3.35 \text{ dBA} \]

**Figure 33** ISO (RIGHT EAR) VERSUS CSA-HIGHWAY
$N_{ISO} = 31.25 \text{ (CSA)} - 2564.06$

$r = 0.66$

$\sigma_y = 60.41\%$

$\sigma_x = 2.95 \text{ dBA}$
$ND_{POIR} = 22.74 \text{ (CSA)} - 1817.73$

$r = 0.66$

$\sigma_y = 48.42\%$

$\sigma_x = 3.22 \text{ dBA}$

FIGURE 35 POIR (RIGHT EAR) VERSUS CSA-CITY
\[ N_D_{POIR} = 34.48 \text{ (CSA)} - 2774.9 \]

\[ r = 0.77 \]

\[ \sigma_y = 77.19\% \]

\[ \sigma_x = 3.35 \text{ dBA} \]
\[ N_{D, POIR} = 32.26 (CSA) - 2567.79 \]

- \( r = 0.69 \)
- \( \sigma_y = 66.61\% \)
- \( \sigma_x = 2.95 \text{ dBA} \)

Figure 37. POIR (Right Ear) Versus CSA-Freeway
Predicted 8hr noise dose at right ear (%)

ND (PREDICTED) = 0.487 DOSIMETER + 54.80

r = 0.44

σ_y = 35.10%

σ_x = 32.06%

Figure 38: Dosimeter 8 hr reading versus predicted 8 hr noise dose at right ear.
ND (PREDICTED) = 1.02 DOSIMETER + 26.12

\[ r = 0.47 \]

\[ \sigma_y = 71.65\% \]

\[ \sigma_x = 33.18\% \]

**FIGURE 39** DOSIMETER 8 HR READING VERSUS PREDICTED 8 HR NOISE DOSE AT LEFT EAR
Figure 40: Dosimeter 8 hr. reading versus ear bug noise dose at right ear.
<table>
<thead>
<tr>
<th>VIN</th>
<th>FWD</th>
<th>Year</th>
<th>V8</th>
<th>Type</th>
<th>HP</th>
<th>RPM</th>
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TABLE 2

ENG SPECIFICATIONS

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<th>TYPE</th>
<th>DISPL. AND TRANS.</th>
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**TABLE 3**

RESULTS FOR BUSES

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<th>VEHICLE</th>
<th>$L_{eq}$ - dBA</th>
<th>NOISE DOSE - % BASED CN 8hr DAY</th>
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<td>D</td>
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### TABLE 4
VALUES FOR $L_{10}$

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<th>$L_{eq}(CITY)$ - dBA</th>
<th>$L_{eq}(HIGHWAY)$ - dBA</th>
<th>$L_{eq}(FREEWAY)$ - dBA</th>
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<td>MICRPHONE POSITION</td>
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*Windows Partially Open

**Windows Closed - Window Vent Open
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*Windows Partially Open
**Windows Closed - Window Vent Open
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**Noise Dose Exposure coronary**

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**NOISE EXPOSURE DATA**

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* Window Partially Open
** Vent Window Open
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**Noise Dose Exposure OSHA**

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**TABLE 6: NOISE DOSE EXPOSURE OSPAR**
**TABLE 7**

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**NOISE DOSE EXPOSURE ISO P1000**

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**TABLE 9**

Noise Dose Exposure for...
### Table 10

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**Note:** For a particular vehicle, the noise levels shown were recorded simultaneously at the three measuring stations.
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<td>54</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>26</td>
<td>40</td>
<td>44</td>
<td>55</td>
<td>69</td>
<td>79</td>
</tr>
<tr>
<td>27</td>
<td>170</td>
<td>105</td>
<td>56</td>
<td>61</td>
<td>79</td>
</tr>
<tr>
<td>28</td>
<td>86</td>
<td>78</td>
<td>57</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>29</td>
<td>85</td>
<td>47</td>
<td>58</td>
<td>47</td>
<td>65</td>
</tr>
</tbody>
</table>

**COMPARISON OF DOSIMETER READING AND EAR BUG NOISE DOSE AT RIGHT EAR**
APPENDIX A

GOVERNING EQUATIONS FOR THE PERMISSIBLE EXPOSURE

ACCORDING TO OSHA, POIR AND ISO R1999

I OSHA Regulation Applicable for OSHA1A, OSHA1B and OSHA1C

The permissible sound level exposure for continuous noise, should not exceed eight hours for a sound level of 90 dBA with a doubling rate of 5 dBA. This is represented in the following table.

**TABLE 14**

OSHA PERMISSIBLE TIME (IN HOURS) OF EXPOSURE

<table>
<thead>
<tr>
<th>OSHA1A SOUND LEVEL IN dBA</th>
<th>105</th>
<th>100</th>
<th>95</th>
<th>90</th>
<th>85</th>
<th>80</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIME IN HOURS</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>16</td>
<td>32</td>
<td>64</td>
</tr>
</tbody>
</table>

The above table is also shown in Figure 2 which is presented in a graphical form.

The equation to describe this standard can be represented by a straight line formula of the form,

\[
\log(Y) = \log(K) + \left[ a' \ast (X) \right]^{1-A}
\]

where, \( Y \) is the time in hours

\( X \) is the average sound level in dBA.
K is the y-intercept at X = 0
a' is the slope of the line

(note: \( \log = \log_{10} \) unless otherwise indicated)

Hence, the slope \( a' \) from Figure 2 is:

\[
a' = \frac{\Delta Y}{\Delta X} = \frac{\log(8.0) - \log(4.0)}{90.0 - 95.0}
\]

\[
a' = \frac{0.903 - 0.602}{-5.0}
\]

\[
a' = -0.0602
\]

Solving for constant \( K \), knowing that for \( X = 50 \) dBA and \( Y = 2048 \) hours.

Since \( \log(Y) = \log(K) + \left[a' \times (X)\right] \)

then

\[
3.311 = \log(K) - \left[0.0602 \times (50.0)\right]
\]

therefore,

\[
\log(K) = 6.321
\]

The equation 1-A becomes,

\[
\log(Y) = 6.321 - \left[0.0602 \times (X)\right]
\]

II POIR Regulation

Similar derivation may be made for OSHA1B which limits 85 dBA for 8 hours = 100\% (q = 5).

\[
\log(Y) = 6.021 - \left[0.0602 \times (X)\right]
\]

III ISO-R1999 Regulation

\[
\log(Y) = 9.933 - \left[0.1003 \times (X)\right]
\]

Equations 5-A, 6-A and 7-A are applicable for any cut-off.
APPENDIX B

EXPRESSIONS FOR THE EQUIVALENT SOUND LEVEL

I  Fundamental Definition of $L_{eq}$

$L_{eq}$, as previously defined, is the level of the steady state continuous noise having the same energy as the actual time varying noise. This can be expressed in mathematical terms as,

$$L_{eq} = \left[ \frac{q}{\log(2)} \right] \ast \log \left\{ \frac{1}{T} \int_0^T \left[ \frac{P(t)}{P_o} \right]^{\frac{20 \log(2)}{q}} dt \right\}$$

1-B

where, $q$ is the number of dBA to be added to a noise level to give the same noise dose if the duration is halved.

$P_o = 2 \times 10^{-5}$ N/m$^2$ is the reference sound pressure.

$P(t)$ is the A-weighted time varying sound pressure in N/m$^2$.

$T$ is the measurement duration.

1. For ISO 1999 Regulation where $q = 3$

then,

$$L_{eq} = \left[ \frac{3}{\log(2)} \right] \ast \log \left\{ \frac{1}{T} \int_0^T \left[ \frac{P(t)}{P_o} \right]^{\frac{20 \log(2)}{3}} dt \right\}$$

2-B

$$L_{eq} = (9.965) \ast \log \left\{ \frac{1}{T} \int_0^T \left[ \frac{P(t)}{P_o} \right]^{2.007} dt \right\}$$

3-B
or,

\[ L_{eq} = (10) \times \log \left\{ \frac{1}{T} \int_{0}^{T} \left[ \frac{P(t)}{P_o} \right]^2 \, dt \right\} \]

2. **For the OSHA Regulation where \( q = 5 \)**

Therefore,

\[ L_{os} = \left[ \frac{5}{\log(2)} \right] \times \log \left\{ \frac{1}{T} \int_{0}^{T} \left[ \frac{P(t)}{P_o} \right]^{\frac{20 \log(2)}{5}} \, dt \right\} \]

\[ L_{os} = (16.609) \times \log \left\{ \frac{1}{T} \int_{0}^{T} \left[ \frac{P(t)}{P_o} \right]^{1.204} \, dt \right\} \]

Hence,

\[ L_{os} = (16.609) \times \log \left\{ \frac{1}{T} \int_{0}^{T} \left[ \frac{P(t)}{P_o} \right]^{1.2} \, dt \right\} \]

II **Equivalent Noise Level as a Function of Noise Dose and Time**

It is often convenient to determine the equivalent sound level from noise dose measurements (such as noise dosimeters). For such computation one would refer to line chart diagrams, however this is not very accurate and rather inconvenient for computer techniques. Equations to determine these relationships are derived in this section.
1. **ISO R1999 Regulation**

Equivalent sound level versus noise dose based on the ISO R1999 standard is presented in Figure 41. This is a plot of \( L_{eq} \) versus ND on semilog paper.

Therefore, the equations are of the form,

\[
L_{eq} = \left[ m_1 \log(ND) \right] + b_1
\]

where, \( m_1 \) is the slope

\( b_1 \) is the y-intercept

The slopes are constant and can be calculated from the line represented for 8 hours.

\[
\text{Slope } m_1 = \frac{\Delta Y}{\Delta X} = \frac{90.0 - 85.0}{\log(100.0) - \log(30.0)} = \frac{5.0}{0.523} = 9.562
\]

The intercept for a given time is represented in Figure 44 for all values at ND = 12. For the ISO R1999 standard the following equation describes the relationship,

\[
\log(L_{eq}) = \left[ -0.055 \log(T) \right] + \log(79.5)
\]

or,

\[
L_{eq} = (79.5) \cdot (T^{-0.055})
\]

Therefore the following relationship exists for \( L_{eq} \) as a function of ND and T,

\[
L_{eq} = \left[ 9.562 \log(ND) \right] + 79.5 \cdot (T^{-0.055})
\]
2. **OSHA Regulation**

A similar equation can be shown for the OSHA regulation (90 dBA for 8 hours = 100%, q = 5),

The equation is of the form,

\[ L_{os} = \left[ m_3 \ast \log(ND) \right] + b_3 \]  

where,

- \( L_{os} \) is the average sound level in dBA
- \( m_3 \) is the slope
- \( ND \) is the noise dose in percent
- \( b_3 \) is the y-intercept

The slope, \( m_3 \), is calculated (see Figure 42)

\[ m_3 = \frac{90.0 - 85.0}{\log(100.0) - \log(50.0)} \]

\[ = \frac{5.0}{0.301} = 16.609 \]  

From the log-log plot of intercepts versus time in Figure 43

\[ m_4 = \frac{\log(72.0) - \log(55.6)}{\log(10^0) - \log(1^1)} \]

\[ m_4 = -0.112 \]

where, \( m_4 \) is the slope of the line represented in Figure 44.

Hence, the OSHA line in Figure 44 can be represented as,

\[ \log(L_{os}) = \left[ -0.112 \ast \log(T) \right] + \log(72.0) \]  

or,

\[ L_{os} = 7.20 \ast (T^{-0.112}) \]

Expressing \( L_{os} \) as a function of \( ND \) and \( T \),

\[ L_{os} = \left[ 16.609 \ast \log(ND) \right] + (72.0) \ast (T^{-0.112}) \]
3. **POIR Regulation**

Similarly for the POIR regulation, 85 dBA for 8 hours = 100%

(q = 5),

\[
L_{os} = \left[ 16.609 \times \log(ND) \right] + 67.0 \times T^{-0.122}
\]

19-8
FIGURE 41  \( L_{os} \) VERSUS OSHA NOISE DOSE
$L_{os}$ - dBA

$\text{NOISE DOSE} \quad \%$

$1 \text{ hr.}$, $2 \text{ hr.}$, $4 \text{ hr.}$, $8 \text{ hr.}$

\text{FIGURE 42} \quad L_{os} \text{ VERSUS POIR NOISE DOSE}
FIGURE 44  Y-INTERCEPT VERSUS TIME
(refer to Figures 41, 42 and 43 for y-intercepts data)
APPENDIX C

NOISE DOSE EXPOSURE

I Noise Dose Meter Evaluation of Noise Exposure

The following equation evaluates the noise dose of a particular time varying sound,

$$\text{ND} = (100.0) \times \int_0^{T/8} \left( \frac{P(t)}{0.632} \right)^n \, dt$$  \hspace{1cm} 1-C

where, $P(t)$ is the A-weighted time varying sound pressure in Pascals.

$T$ is the measurement duration in hours.

ND is the noise dose in percent.

II For the ISO R1999 Regulation

The basic definition of sound level is,

$$L_p = (20.0) \times \log \left( \frac{P_m}{P_0} \right)$$  \hspace{1cm} 2-C

or,

$$L_p = 10 \times \log \left( \frac{P_m^2}{P_o} \right)$$  \hspace{1cm} 3-C

where, $P_m$ = sound pressure in N/m$^2$ (note: Pa $\equiv$ N/m$^2$)

$P_o$ = reference sound pressure, $2 \times 10^{-5}$ N/m$^2$

$L_p$ = sound level in dB

rearranging, $P_m = P_o \times \left( \frac{L_p}{20} \right)$  \hspace{1cm} 4-C
To solve for "n" in Equation 1-C, equate the following conditions,

(i) 90 dBA for 8 hours

and, (ii) 93 dBA for 4 hours

thus, for 90 dBA

\[ P_m = P_o \times 10^{L_p/20} \]

\[ = 2 \times 10^{-5} \times 10^{90/20} \]

\[ = 0.632 \text{ N/m}^2 \]

similarly for 93 dBA,

\[ P_m = 0.894 \text{ N/m}^2 \]

rewriting mathematically,

\[ \int_0^{4/8} \left[ \frac{0.894}{0.632} \right]^n dt = \int_0^{8/8} \left[ \frac{0.632}{0.632} \right]^n dt \]

\[ = 1.441^n \times t \bigg|_0^{4/8} = 1^n \times t \bigg|_0^{8/8} \]

solving for n,

\[ n = 2 \]

therefore,

\[ N_{D,ISO} = 100 \times \int_0^{T/8} \left[ \frac{P(t)}{0.632} \right]^2 dt \]
III  For the OSHA Regulation

Knowing that \( q = 5 \)
implies, 90 dBA for 8 hours
and 95 dBA for 4 hours

In the same way as in part II, one would obtain \( n = 1.2 \)

Therefore,

\[
\frac{T}{8} \quad 1.2
\]

\[
ND_{OSHA} = 100 \times \int_{0}^{T/8} \left[ \frac{P(t)}{0.632} \right] \, dt
\]

IV  Equivalent Noise Dose Evaluation

Noise dose may be calculated from statistical information.

The equation is of the form,

\[
ND = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n} \right) \times 100
\]

where, \( C_n \) is the actual time in hours spent in the nth sound level.
\( T_n \) is the maximum permissible time in hours for the nth sound level.

Equations 9-C and 10-C would yield the same noise dose as in Equation 11-C, however this is dependent on the chosen standard. Overexposure would imply 100%, indicating a hazardous working environment.
APPENDIX D

LINEAR REGRESSION

The linear relationship is of the form,

\[ y_m = a + (b \times x_m) \tag{1-D} \]

where, \( m \) denotes pairs of data points \((x_1, y_1), (x_2, y_2), \ldots, (x_m, y_m)\).

The derivation of the data point can be calculated from the equation \((a + bx_i - y_i)\). The choice of "a" and "b" is such that,

\[ \sum_{i=1}^{m} (a + bx_i - y_i)^2 \rightarrow \text{minimum} \tag{2-D} \]

The minimum occurs when the partial derivative of Equation 2-D with respect to "a" and "b" equals zero.

\[ \frac{\partial}{\partial a} \sum_{i=1}^{m} (a + bx_i - y_i)^2 = \sum 2 \times (a + bx_i - y_i) = 0 \tag{3-D} \]

and,

\[ \frac{\partial}{\partial b} \sum_{i=1}^{m} (a + bx_i - y_i)^2 = \sum 2 \times (a + bx_i) \times x_i - y_i = 0 \tag{4-D} \]

Dividing by 2 and separating Equations 3-D and 4-D into individual terms,

\[ m \times a + b \times \sum x_i = \sum y_i \tag{5-D} \]
\[ a \cdot \sum x_i + b \cdot \sum x_i^2 = \sum x_i \cdot y_i \]

solving Equations 5-D and 6-D simultaneously to obtain:

\[ a = \frac{\sum x_i^2 \cdot \sum y_i - \sum x_i \cdot (\sum x_i \cdot y_i)}{\sum x_i^2 - (\sum x_i)^2} \]

\[ m = \frac{\sum y_i - \sum x_i \cdot \sum y_i}{\sum x_i^2 - (\sum x_i)^2} \]

and,

\[ b = \frac{m \cdot (\sum x_i \cdot y_i) - \sum x_i \cdot \sum y_i}{\sum x_i^2 - (\sum x_i)^2} \]

The following assumptions apply to the above equations:

(a) \( y \) is a linear function of an independent variable \( x \)
(b) The deviations are measured in the direction of the \( y \)-axis
(c) \( x \) is either free from error or subject to negligible error only
(d) \( y \) is observed or measured quantity subject to errors which have to be eliminated by the method of least square
(e) Observed values of \( y_i \) corresponds to assigned values of \( x_i \)
APPENDIX E

SAMPLE CALCULATION

The analysis for vehicle no. 1 for freeway driving and microphone position at the drivers right ear is illustrated.

The data from the Metrosonic db-601 is given as follows:

(a) Total freeway driving time = 3 hours, 55 minutes = 253 minutes
(b) $L_{eq}$ (ISO R1999) = 89 dBA
(c) $P_1$ scan - refer to Table 15.0

TABLE 15

TABULAR RESULTS FOR $P_1$ SCAN FROM METROSONICS db-601 - VEHICLE NO.1

<table>
<thead>
<tr>
<th>No.</th>
<th>SPL($L_p$)</th>
<th>$P_1$ scan</th>
<th>Time in each level minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dBA</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>72</td>
<td>0.2</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>0.2</td>
<td>0.47</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>0.3</td>
<td>0.71</td>
</tr>
<tr>
<td>4</td>
<td>75</td>
<td>0.9</td>
<td>2.11</td>
</tr>
<tr>
<td>5</td>
<td>76</td>
<td>0.6</td>
<td>1.41</td>
</tr>
<tr>
<td>6</td>
<td>77</td>
<td>0.4</td>
<td>0.94</td>
</tr>
<tr>
<td>7</td>
<td>78</td>
<td>0.3</td>
<td>0.71</td>
</tr>
<tr>
<td>8</td>
<td>79</td>
<td>0.9</td>
<td>2.11</td>
</tr>
<tr>
<td>9</td>
<td>80</td>
<td>0.3</td>
<td>0.71</td>
</tr>
<tr>
<td>10</td>
<td>81</td>
<td>0.5</td>
<td>1.18</td>
</tr>
<tr>
<td>11</td>
<td>82</td>
<td>0.6</td>
<td>1.41</td>
</tr>
<tr>
<td>12</td>
<td>83</td>
<td>1.2</td>
<td>2.82</td>
</tr>
<tr>
<td>13</td>
<td>84</td>
<td>2.9</td>
<td>6.81</td>
</tr>
<tr>
<td>14</td>
<td>85</td>
<td>5.0</td>
<td>11.75</td>
</tr>
<tr>
<td>15</td>
<td>86</td>
<td>7.7</td>
<td>18.09</td>
</tr>
<tr>
<td>16</td>
<td>87</td>
<td>14.4</td>
<td>33.84</td>
</tr>
<tr>
<td>17</td>
<td>88</td>
<td>22.6</td>
<td>54.11</td>
</tr>
<tr>
<td>18</td>
<td>89</td>
<td>23.1</td>
<td>54.29</td>
</tr>
<tr>
<td>19</td>
<td>90</td>
<td>13.0</td>
<td>30.55</td>
</tr>
<tr>
<td>20</td>
<td>91</td>
<td>4.4</td>
<td>10.34</td>
</tr>
<tr>
<td>21</td>
<td>92</td>
<td>1.1</td>
<td>2.59</td>
</tr>
<tr>
<td>22</td>
<td>93</td>
<td>0.3</td>
<td>0.7</td>
</tr>
<tr>
<td>23</td>
<td>94</td>
<td>0.2</td>
<td>0.47</td>
</tr>
</tbody>
</table>
I Calculate the Time Spent in Each Sound Level

\[
\text{Time in each sound level} = \frac{P \text{ scan} \times \text{total time}}{100.0}
\]

where, \( n = 1, 2, 3 \ldots m \) (real)

therefore at \( L_p = 72 \text{ dBA} \),

Time spent at 72 dBA = \( \frac{0.2 \times 2.35}{100.0} \) = 0.47 minute

This is calculated for each sound level and is entered in Table 15.

II \( L_{eq} \) check

\[
L_{eq} = 10.0 \times \log \left( \frac{1}{T} \sum_{i=1}^{N} \frac{L_i}{10} \times t_i \right)
\]

where, \( T \) is the total time in hours

\( L_i \) is the \( i \)th sound level in dBA

\( t_i \) is the \( i \)th time in hours

\( i = 1, 2, \ldots N \) (real)

III Noise Dose - OSHA/LA Regulation (90 dBA = 100% for 8 Hours,

Range 90 to 115 dBA; \( q = 5 \))

\[
ND = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots \frac{C_n}{T_n} \right) \times 100.0
\]

(see Equation 11-C)

where, \( T_i' = \text{antilog} \left[ 6.321 - \left( 0.0602 \times (L_i) \right) \right] \) in hours.

\( C_i \) is the actual time in hours as calculated in Table 16.0
\[ ND = \left( \frac{30.55}{T_{90}} + \frac{10.34}{T_{91}} + \frac{2.59}{T_{92}} + \frac{0.70}{T_{93}} + \frac{0.47}{T_{94}} \right) \times 100.0 \]

\[ = 9.94\% \]

Noise dose for 8 hours,

\[ ND_8 = 9.94 \times \frac{8.0}{3.5} \]

\[ ND_8 = 20\% \]

IV Noise Dose - OSHA1B Regulation (90 dBA = 100% for 8 Hours, Range 85 to 115 dBA; \( q = 5 \))

since,

\[ ND = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \ldots + \frac{C_n}{T_n} \right) \times 100.0 \]

and,

\[ T'_i = \text{antilog} \left[ 6.321 - \left( 0.0602 \times (L_i) \right) \right] \text{ in hours} \]

then,

\[ ND = \left( \frac{11.75}{T'_{85}} + \frac{18.09}{T'_{86}} + \frac{33.84}{T'_{87}} + \frac{53.11}{T'_{88}} + \frac{54.29}{T'_{89}} \right. \]

\[ + \frac{30.55}{T'_{90}} + \frac{10.34}{T'_{91}} + \frac{2.59}{T'_{92}} + \frac{0.70}{T'_{93}} + \frac{0.47}{T'_{94}} \left. \right) \times 100.0 \]

\[ ND = 72.36\% \]

Noise dose for 8 hours,

\[ ND_8 = 72.36 \times \frac{8.0}{3.5} \]

\[ ND_8 = 147.79\% \]
V. Noise Dose - ISO R1999 Regulation (90 dBA = 100% for 8 Hours, Range 80 to 130 dBA; q = 3)

since,

\[ ND = \left( \frac{C_1}{T_1} + \frac{C_2}{T_2} + \cdots + \frac{C_n}{T_n} \right) \times 100.0 \]

and,

\[ T_i = \text{antilog} \left[ 9.933 - \left( 0.1003 \times (L_i) \right) \right] \text{ in hours} \]

\[ ND = \left( \frac{0.71}{T_{80}} + \frac{1.18}{T_{81}} + \frac{1.41}{T_{82}} + \frac{2.82}{T_{83}} + \frac{6.81}{T_{84}} + \frac{11.75}{T_{85}} \right. \]
\[ + \left. \frac{18.09}{T_{86}} + \frac{33.84}{T_{87}} + \frac{53.11}{T_{88}} + \frac{54.29}{T_{89}} + \frac{30.55}{T_{90}} \right. \]
\[ + \left. \frac{10.34}{T_{91}} + \frac{2.59}{T_{92}} + \frac{0.70}{T_{93}} + \frac{0.47}{T_{94}} \right) \times 100.0 \]

\[ ND = 32.78\% \]

Noise dose for 8 hours,

\[ ND_8 = 32.78 \times \frac{8.0}{3.55} \]

\[ ND_8 = 66.95\% \]

VI. Predicted Noise Dose for the Right Ear Based on OSHA\&C Regulation

\[ ND_{OSHA\&C} = \frac{T_{city}}{8} \times \left[ 11.6 \times (CSA) - 931.7 \right] + \]

\[ \frac{T_{highway}}{8} \times \left[ 10.9 \times (CSA) - 864.1 \right] + \]

\[ \frac{T_{freeway}}{8} \times \left[ 16.4 \times (CSA) - 1304.75 \right] \]
For vehicle no. 23, given data are the following:

- CSA standard = 87 dBA
- \( T_{\text{city}} = 0.32 \) hour
- \( T_{\text{highway}} = 1.32 \) hours
- \( T_{\text{freeway}} = 6.7 \) hours

\[
\begin{align*}
ND &= \frac{32}{8} \ast (80.1) + \frac{1.32}{8} \ast (92.1) + \frac{6.7}{8} \ast (122.0) \\
&= 3.2 + 15.2 + 102. = 120.6
\end{align*}
\]

Noise dose for 8 hours:

\[
\begin{align*}
ND_8 &= 120.6 \ast \frac{8}{8.08} \\
&= 115.8
\end{align*}
\]

VII Predicted Noise Dose for Left Ear Based on OSHA1C Regulation

\[
\begin{align*}
ND_{\text{OSHA1C}} &= \frac{T_{\text{city}}}{8} \ast \left[ 9.71 \ast (\text{CSA}) - 755.3 \right] + \\
&\quad \frac{T_{\text{highway}}}{8} \ast \left[ 13.2 \ast (\text{CSA}) - 1038.4 \right] + \\
&\quad \frac{T_{\text{freeway}}}{8} \ast \left[ 37.0 \ast (\text{CSA}) - 3068.9 \right]
\end{align*}
\]

For vehicle no. 23, given data are the following:

- CSA standard = 87 dBA
- \( T_{\text{city}} = 0.30 \) hour
- \( T_{\text{highway}} = 1.45 \) hours
- \( T_{\text{freeway}} = 6.22 \) hours
thus,

\[
ND = \frac{3}{8} \times (79.4) + \frac{1.45}{8} \times (106.5) + \frac{6.22}{8} \times (153.6)
\]

\[
= 2.9 + 19.3 + 119.4
\]

\[
= 141.7\%
\]

Noise dose for 8 hours,

\[
ND = \frac{8.0}{7.9} \times 141.7
\]

\[
ND = 143.5\%
\]
APPENDIX F

CORRELATED EQUATIONS

1. OSHAIC Noise Dose Versus CSA Z107.23

A. Right Ear

\[
\text{ND}_{\text{OSHAIC}} = 11.63 \times (\text{CSA}) - 931.74, \text{ city } (r = 0.66) \quad 1-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 10.99 \times (\text{CSA}) - 864.07, \text{ highway } (r = 0.77) \quad 2-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 16.4 \times (\text{CSA}) - 1304.75, \text{ freeway } (r = 0.69) \quad 3-F
\]

B. Left Ear

\[
\text{ND}_{\text{OSHAIC}} = 9.71 \times (\text{CSA}) - 765.34, \text{ city } (r = 0.71) \quad 4-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 13.6 \times (\text{CSA}) - 1038.42, \text{ highway } (r = 0.78) \quad 5-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 37.04 \times (\text{CSA}) - 3068.89, \text{ freeway } (r = 0.34) \quad 6-F
\]

C. Center of Cab

\[
\text{ND}_{\text{OSHAIC}} = 7.75 \times (\text{CSA}) - 610.0, \text{ city } (r = 0.89) \quad 7-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 12.35 \times (\text{CSA}) - 991.48, \text{ highway } (r = 0.74) \quad 8-F
\]

\[
\text{ND}_{\text{OSHAIC}} = 20.83 \times (\text{CSA}) - 1694.79, \text{ freeway } (r = 0.42) \quad 9-F
\]

2. POIR Noise Dose Versus CSA Z107.23

D. Right Ear

\[
\text{ND}_{\text{POIR}} = 22.74 \times (\text{CSA}) - 1817.73, \text{ city } (r = 0.66) \quad 10-F
\]

\[
\text{ND}_{\text{POIR}} = 34.48 \times (\text{CSA}) - 2774.9, \text{ highway } (r = 0.77) \quad 11-F
\]

\[
\text{ND}_{\text{POIR}} = 32.26 \times (\text{CSA}) - 2557.74, \text{ freeway } (r = 0.69) \quad 12-F
\]

E. Left Ear

\[
\text{ND}_{\text{POIR}} = 27.78 \times (\text{CSA}) - 2233.3, \text{ city } (r = 0.65) \quad 13-F
\]

\[
\text{ND}_{\text{POIR}} = 20.83 \times (\text{CSA}) - 1618.7, \text{ highway } (r = 0.73) \quad 14-F
\]

\[
\text{ND}_{\text{POIR}} = 66.67 \times (\text{CSA}) - 5464.67, \text{ freeway } (r = 0.36) \quad 15-F
\]
F. Center of Cab
\[
\begin{align*}
ND_{POIR} &= 14.49 \times (CSA) - 1132.32, \text{ city } (r = 0.74) \quad 16-F \\
ND_{POIR} &= 17.24 \times (CSA) - 1353.79, \text{ highway } (r = 0.74) \quad 17-F \\
ND_{POIR} &= 30.30 \times (CSA) - 2435.15, \text{ freeway } (r = 0.43) \quad 18-F
\end{align*}
\]

3. ISO R1999 Noise Dose Versus CSA Z107.23

G. Right Ear
\[
\begin{align*}
ND_{ISO} &= 16.13 \times (CSA) - 1321.29, \text{ city } (r = 0.65) \quad 19-F \\
ND_{ISO} &= 17.54 \times (CSA) - 1427.37, \text{ highway } (r = 0.75) \quad 20-F \\
ND_{ISO} &= 31.25 \times (CSA) - 2564.06, \text{ freeway } (r = 0.66) \quad 21-F
\end{align*}
\]

H. Left Ear
\[
\begin{align*}
ND_{ISO} &= 19.23 \times (CSA) - 1583.27, \text{ city } (r = 0.59) \quad 22-F \\
ND_{ISO} &= 18.87 \times (CSA) - 1536.98, \text{ highway } (r = 0.67) \quad 23-F \\
ND_{ISO} &= 90.91 \times (CSA) - 7662.73, \text{ freeway } (r = 0.31) \quad 24-F
\end{align*}
\]

I. Center of Cab
\[
\begin{align*}
ND_{ISO} &= 12.05 \times (CSA) - 981.20, \text{ city } (r = 0.85) \quad 25-F \\
ND_{ISO} &= 20.83 \times (CSA) - 1723.13, \text{ highway } (r = 0.67) \quad 26-F \\
ND_{ISO} &= 500 \times (CSA) - 42370.0, \text{ freeway } (r = 0.08) \quad 27-F
\end{align*}
\]
APPENDIX G

SOUND LEVEL FOR TRUCK CAB INTERIOR

- SAE J366a RECOMMENDED PRACTICE
SOUND LEVEL FOR TRUCK CAB
INTERIOR—SAE J336a

SAE Recommended Practice

1. Introduction

This SAE Recommended Practice describes the equipment and procedure for determining the maximum truck cab interior sound level. This practice applies to motor trucks and truck tractors and does not include construction and industrial machinery. The appendix contains SAE recommended design criteria for new vehicles.

2. Instrumentation

The following instrumentation shall be used, where available, for the measurement required:

2.1 A sound level meter which meets the Type 1 requirements of ANSI S1.4-1971, Specification for Sound Level Meters.

2.2 A set of octave bandpass filters which meet the Class II requirements of ANSI S1.1-1966, Specification for Octave, Half-Octave and Third-Octave Band Filter Sets.

As an alternative to making direct measurements with a sound level meter and octave band filter set, a microphone or sound level meter may be used with a magnetic tape recorder and/or a graphic level recorder or indicating meter, provided that the system used meets the requirements of SAE J336.

2.3 A sound level calibrator (see paragraph 4.2.3).

2.4 An engine-speed tachometer.

3. Test Procedure

The following procedure is to be used for the measurement of this SAE Recommended Practice.

3.1 Establish a seat reference point at the intersection of the tangent lines to the predominant surfaces of the undeflected cushion and backrest at the seat center of the seat (or intended operator location). Adjust the seat to the midpoint of its horizontal and vertical travel. Locate the microphone, oriented vertically upward, at a point 29 in (740 mm) vertically above the seat reference point and 10 in (250 mm) laterally to the right (to the left for right-hand drive vehicles) of the seat reference point.

Position the driver so that his ear is reasonably aligned with, and approximately 6 in (150 mm) laterally from, the microphone. Seat adjustment may be made to meet this provision.

3.2 Sound level tests may be conducted with or without a trailer or loads on the vehicle.

3.3 On vehicles equipped with radiator shutters, the shutter position yielding the maximum sound level should be determined and the tests conducted with the shutters in that position.

3.4 Vehicle windows and vents are to be in the fully closed position with all accessories "off."
MEASUREMENT OF EXTERIOR SOUND LEVELS
FOR HEAVY TRUCKS UNDER STATIONARY CONDITIONS—SAE J1096

1. Introduction. This SAE Recommended Practice establishes the test procedure, environment, and instrumentation for determining the maximum exterior sound level of heavy trucks with governed engines under stationary vehicle conditions. The basic procedure involves a full throttle engine acceleration and a closed throttle deceleration with the engine mating as the load.

2. Instrumentation—The following instrumentation shall be used, where applicable, for the measurement required:

- A sound level meter which satisfies the Type 1 requirements of American National Standard Specification for Sound Level Meters, SI 4.9.1.

2.1 A sound level meter which satisfies the Type 1 requirements of American National Standard Specification for Sound Level Meters, SI 4.9.1.

2.2 As an alternative to making direct measurements using a sound level meter, a microphone or sound level monitor may be used with a magnetic tape recorder and/or a graphic level recorder or other indicating instrument providing the system meets the requirements of SAE Recommended Practice J1091, Qualifying a Sound Data Acquisition System.

2.3 A sound level meter, accurate to ±0.5 decibel shall be used, as shown in Figure 5.3.

3. Procedure

3.1 The test area (defined as shown in Figure 1) shall be surfaced with concrete, asphalt, or similar hard non-porous material, and shall be free of snow, grass, and other sound-absorbing materials.

3.2 The microphone shall be located 1.5 m (5 ft) from the centerline of the truck, and 0.6 m (2 ft) above the ground plane as shown in Figure 1. The microphone shall be located on a line perpendicular to the vehicle centerline and parallel to the test site.

3.3 Because bystanders have an appreciable influence on meter response, the observer shall observe the vehicle on the microphone, not more than 15 m (50 ft) from the microphone, and shall be within 15 m (50 ft) of the vehicle or instrument, and that person shall be directly behind the observer reading the meter on a line through the microphone and observer.

3.4 The ambient sound level (including wind effects) coming from the vehicle being measured shall be at least 10 dB lower than the level of the tested vehicle.

4. Measurements

4.1 The vehicle shall be tested in a stationary position with maximum engine acceleration and deceleration with no external load applied.

4.2 The engine governor and throttle of a closed throttle deceleration cycle. The applicable reading shall be the highest sound level obtained during this cycle. Unrelated peaks due to unusual ambient noise should be ignored.

4.3 The sound level at each side of the vehicle shall be the average of the last two highest readings which are within 1 dB of each other. Report the sound level for the side of the vehicle with the highest average value.
APPENDIX H

PROPOSED DRAFT CSA STANDARD Z107.23
PROCEDURE FOR MEASUREMENTS OF THE MAXIMUM INTERIOR SOUND LEVEL IN TRUCKS WITH GOVERNEED DIESEL ENGINES

NOTE: This is not an adopted Standard but is a draft for critical review and comment only.

CANADIAN STANDARDS ASSOCIATION

Fifth draft October 1976

CSA Sub-Committee on Transport Vehicle Noise

Control of the noise exposure of commercial vehicle drivers depends on the availability of simple, repeatable measurement procedures which can be readily applied in practice. This Standard is intended to provide such a procedure for trucks with governed diesel engines. It therefore forms a suitable basis for voluntary or statutory control of the noise exposure of the drivers of such trucks in current use on the road.

REFERENCE PUBLICATIONS

This Standard refers to the publications listed below. The year dates shown indicate the latest issues available at the date of printing of the present Standard.

1.1 This Standard defines a procedure for measuring the maximum interior sound level in the region of the driver's ear in trucks with governed diesel engines. The measurements are made with the vehicle stationary and the transmission in neutral. The Standard applies to trucks designed primarily for use on the road.

1.2 The procedure defined in this Standard is primarily intended as a basis for voluntary or statutory control of the noise exposure of drivers of vehicles in use. The procedure contains nothing, however, which precludes its use in certifying the performance of new vehicles.

2. INSTRUMENTATION

2.1 The following instrumentation shall be used:

(a) a sound level meter which meets or exceeds the Type 2 requirements of CSA Standard 2107.1, Specification for Sound Level Meters;

(b) a sound level calibrator which is capable of calibrating the measurement system at one or more frequencies with an accuracy of ±0.5 dB.

2.2 A combination of the sound level meter with any optional accessories, such as a microphone cable, shall also meet the Type 2 requirements of CSA Standard 2107.1, Specification for Sound Level Meters.

3. ACOUSTICAL ENVIRONMENT

3.1 An acceptable measurement site for the purposes of this Standard shall consist of an open space free of any large reflecting surfaces such as buildings, signboards or other objects located within 7 m of the vehicle under measurement.

3.2 The ambient sound level in the truck cab with the engine switched off shall be at least 10 dB below the minimum sound level reading obtained in accordance with Clause 4.2.6.

4. PROCEDURE

4.1 Vehicle Operation

4.1.1 All vehicle doors, windows and ventilators shall be closed.
4.1.2 All power operated accessories shall be switched off.

4.1.3 The driver shall be seated in his normal operating position.

4.1.4 With the transmission in neutral, the clutch engaged and the engine idling at its normal operating temperature, the throttle shall be fully opened. The governed maximum rate of engine revolution shall be maintained for at least 5 seconds and the engine speed then returned to idle.

4.1.5 Where the vehicle is equipped with thermostatically controlled radiator shutters, the measurements shall be made while the shutters are closed.

4.1.6 Where the vehicle is equipped with a thermostatically controlled fan, the measurements shall be made while the fan is not in operation.

4.2 Measurements

4.2.1 The sound level meter shall be set for slow response and the A-weighting network.

4.2.2 Field calibration of the sound level measuring system shall be performed immediately before and after each sequence of measurements. If a calibration change of more than 1 dB is observed, then the results of the entire sequence shall be rejected.

NOTE: To reduce the risk of rejecting a large number of measurements, calibration should be performed at least at the beginning and end of each day's work. In addition, battery levels should be checked at frequent intervals.

4.2.3 The microphone shall be located between 150 and 200 mm to the right of the driver's right ear, in the same horizontal and vertical transverse planes, and directed forward.

4.2.4 The observer reading the sound level meter shall be the only person in the cab other than the driver. The observer shall, so far as possible, be seated normally in the seating position most remote from the driver.

4.2.5 The ambient sound level in the truck cab shall be observed before the engine is started and after it has been switched off. If the observed ambient sound levels do not conform with the requirements of Clause 3.2, the results of all intermediate measurements shall be rejected.
4.2.6 The sound level meter shall be observed while the vehicle is operated in accordance with Clause 4.1.4. The reading recorded shall be the highest level indicated during the period for which the governed maximum rate of engine revolution is maintained.

4.2.7 At least three readings shall be recorded. If no two readings are within 1 dB of each other, further measurements shall be made until at least one such pair of readings is obtained.

4.2.8 The maximum interior sound level is the average of the highest pair of readings that are within 1 dB of each other.

4.3 Report

4.3.1 Appendix A lists the information which should be included in any comprehensive report of measurements of the maximum interior sound level in a truck with a governed diesel engine conducted in accordance with this Standard.
REPORT ON SOUND LEVEL MEASUREMENTS

NOTE: This Appendix is not a mandatory part of this Standard.

A1. GENERAL

A1.1 This Appendix lists the information which should be included in any comprehensive report of measurements of the maximum interior sound level in a truck with a governed diesel engine conducted in accordance with this Standard.

A2. REPORT CONTENT

A2.1 The report on sound level measurements should include:

(a) a statement that the measurements were conducted in every respect in accordance with the requirements of this Standard;

(b) a list of the instrumentation used, including the manufacturers' names, models and, where applicable, serial numbers;

(c) a description of the environmental conditions at the test site including the level and nature of the ambient noise perceptible inside the cab;

(d) a sketch plan of photograph of the measurement site;

(e) the manufacturer's name, model and vehicle identification number (VIN) of the truck under test;

(f) the manufacturer's name, model and displacement of the engine in litres;

(g) the governed engine speed in revolutions per minute;

(h) a description of the condition of the truck under test with particular reference to any factors which might affect the measured sound levels including the operation of any auxiliary equipment not covered by this Standard;

(i) a list of the sound level readings obtained;

(j) the maximum interior sound level of the truck, expressed to the nearest decibel.
VITA AUCTORIS

Born:

October 25, 1949; Djakarta, Dutch East Indies.

Son of Mrs. Ch.J. Steevensz and the late Mr. J.L. Steevensz.

Education:

Attended secondary schools in Australia, Holland and Canada.


Publications:

Noise Exposure of Truck Drivers. Dr. Z. Reif, T.N. Moore and A. Steevensz. SAE 800278, April 1980. Vehicle Noise Regulation and Reduction.

Professional Affiliations:

Registered Engineer in the Province of Ontario, APEO registration no. 44222016.

Member of the Society of Automotive Engineers, SAE M8378810.

Employment:

Marital Status:

Single.