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UNITED STATES AIR FORCE RESEARCH LABORATORY

Sound Basics: A Primer in Psychoacoustics

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August 1998

Interim Report for the Period March 1997 to July 1998

Human Effectiveness Directorate
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NOTICES

DISCLAIMER

TECHNICAL REVIEW AND APPROVAL

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
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13. ABSTRACT *(Maximum 200 words)*

This report contains materials for human factors professionals who may on occasion be called upon to provide consultation on psychoacoustic problems such as the assessment of occupational and residential noise exposure, prediction of speech intelligibility in noisy environments, and the design and integration of auditory displays. Users of the materials are expected to have a basic understanding of algebraic notation and problem solving and logarithms, but need not have any formal background in psychoacoustics or hearing. Many human factors professionals lack formal training in psychoacoustics and can benefit from the materials presented in this report, which include the general principles of physical acoustics and the measurement of sound, as well as an overview of the physiology and psychology of hearing. The materials were compiled for a workshop conducted by AFRL's Aural Displays and Bioacoustics Branch and provide a reference tool that can serve as a starting point for detailed research of specific applied psychoacoustic problems.

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PREFACE

This report contains materials for human factors professionals who may on occasion be called upon to provide consultation on psychoacoustic problems such as the assessment of occupational and residential noise exposure, prediction of speech intelligibility in noisy environments, and the design and integration of auditory displays. The materials were compiled for a workshop conducted by AFRL's Aural Displays and Bioacoustics Branch (AFRL/HECB). Bartholomew Elias of AFRL/HECB was the principal investigator.

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COURSE DESCRIPTION

Need

Hundreds of human factors professionals are called upon each year to provide consultation and solve problems relating to human hearing and the perception of sound. However, many of these individuals have no formal training in psychoacoustics and have received only a cursory overview of human hearing and acoustics in their education and training. These individuals may be called upon to make assessments of occupational noise exposure, establish guidelines for the design and testing of auditory displays, and predict the intelligibility of speech transmissions in noisy environments to name a few of the many tasks involving applied psychoacoustic research that a human factors professional may be asked to perform. The objective of this course is to provide participants with the knowledge, skills, and ability to address basic applied problems in psychoacoustics. The materials provided to the participant will serve as an invaluable reference tool that can serve as a starting point for detailed research of specific applied psychoacoustic consultations. Since human factors professionals in a variety of fields from industrial and occupational health to aviation to computer science may be called upon to address problems in applied psychoacoustics, it is important that these individuals are afforded the opportunity to obtain formal training to assist them in consulting on these matters. This workshop will allow interested individuals in the human factors profession to gain a basic knowledge of psychoacoustic metrics and methods. The workshop will also expose these individuals to standard acoustic metrics and measurement practices, so that they are better perpared to make appropriate and accurate evaluations of acoustic phenomena and assessments of their impact on humans.

Participants

Prerequisite Experience and Educational Background

Since this is an introductory course, participants are not expected to have any prior knowledge or instruction in acoustics or psychoacoustics. This workshop is an introduction to psychoacoustics for human factors professionals that may occasionally provide consultation on psychoacoustic problems but have no formal educational background in psychoacoustics. Human Factors as a profession attracts individuals of diverse educational backgrounds including engineers, psychologists, sociologists, and individuals with concentrations in basic and applied science. All of these fields of concentration provide the necessary background in analytical thinking and problem solving using the scientific method that is expected for this workshop. Since acoustics and psychoacoustics necessarily involve the introduction of mathematical concepts, participants will be expected to be familiar with basic algebraic problem solving and algebraic notation. If participants have not recently studied or applied these basic mathematical methods, it is recommended that they review some of these concepts prior to the workshop. Since sound intensity is expressed in decibels, a logarithmic quantity, participants should be familiar with mathematical operations involving logarithms and if necessary should review this topic prior to attending the workshop. Participants will be expected to bring a calculator with logarithmic function keys to the workshop as some of the exercises will involve solving simple mathematical problems to derive acoustical quantities such as decibel values. The mathematical principles introduced in this workshop do not go beyond basic algebra and the use of logarithmic scales taught in high schools. Therefore, it is expected that essentially all human factors professionals will have the appropriate experience and educational background to participate in and learn from this workshop.

Knowledge and Skills To Be Acquired

Through participation in this course, individuals will gain broad exposure to the basic concepts and terminology of physical acoustics. Participants will also learn basic practices and procedures for sound measurement. Through a variety of interactive class exercises in problem solving, participants will learn how to set up a basic sound measurement survey and calculate basic sound descriptors from the collected data. Participants will also gain a general understanding of the physiology and psychology of hearing and an awareness of the various research methods employed in psychoacoustic testing. Participants will gain general knowledge and familiarization with key psychoacoustic topics including the perception of loudness and pitch, the perception of temporal patterns in acoustic signals, the assessment of auditory localization capabilities, and the perception of speech. In the second half of the workshop, students will gain the knowledge and skills to apply psychoacoustic methods in the analysis of real world human factors consulting problems. Through class lecture, discussion, and interactive group exercises, participants will learn basic methods for noise analysis in industrial and residential settings as well as methods for assessing the impact of noise on hearing, speech intelligibility, task interference, and annoyance. Participants will be introduced to the practice and procedures of modeling and predicting noise exposure in occupational and residential settings. Additionally, participants will learn about various noise mitigation alternatives such as passive and active noise reduction, noise education, and hearing conservation programs, and will participate in group exercises to help them develop basic skills in evaluating noise problems and making recommendations for mitigation. Finally, students will learn basic concepts, guidelines, and issues regarding auditory display design, and through participation in group exercises will gain experience in designing basic auditory displays and evaluating the effectiveness of auditory displays in complex systems. Since this workshop is an introduction to the basic methods and metrics of psychoacoustics, it is anticipated that participants will be able to use this newly acquired knowledge and skills as a framework to build upon through independent reading and research.

Instructional Methods

The Course

The course will consist of lecture, classroom group problem solving and group exercises, and demonstrations using the Interactive Sound Information System (ISIS) described below. The course will begin with a background discussion of the fundamentals of psychoacoustics, which will describe the physical properties of sound, basic physiology of hearing, and an overview of psychoacoustic methods and metrics. The second half of the course will involve discussion and class exercises to demonstrate the application of psychoacoustic methods to real world consulting problems. Applied issues to be considered include general measurement and assessment of occupational and residential noise exposure, noise modeling, and noise mitigation procedures including the use of passive and active noise reduction devices, education, and the implementation of hearing conservation programs. Finally, applications of psychoacoustics to the design and integration of auditory displays will be discussed.

Fundamentals of Psychoacoustics

In order to provide the participant with a knowledge base of acoustic and psychoacoustic terminology, methods, and metrics, these items will be introduced through lecture and classroom exercises.

The Sound Source

The basic characteristics of sound (its intensity, frequency, and temporal properties) and the measurement of these physical properties will be discussed. The design and use of basic auditory measurement equipment such as microphones, noise level meters, and spectral analyzers will be discussed. Class group exercises will give students experience in computing basic acoustic quantities such as decibel (dB) values.

The Receiver

Basic physiology of the human ear and theories of neural transduction and neural coding will be discussed. Basic psychophysical methods and their application to the study of hearing and the perception of sound will be considered. The measurement and interrelationships between psychoacoustic parameters such as loudness, pitch and temporal patterning will be discussed. Psychoacoustic measurement of auditory localization and theories of spatial hearing will be discussed. Finally, an overview of speech perception at the phonetic level will be discussed and related to topics of speech intelligibility and speech interference in noisy environments which will be revisited in greater detail in the second half of the course. The presentation of these topics will form the groundwork for discussing the application of psychoacoustic methods in human factors consulting projects.

Applied Psychoacoustics

Building upon the fundamental knowledge of acoustic methods and metrics and psychoacoustic procedures, the application of psychoacoustics to real world human factors issues will be considered.

Noise Analysis

Basic metrics of noise analysis will be considered. Building on the concept of the decibel as a sound intensity descriptor, participants will be introduced to the concepts of weighting, summation and spectral analysis. Consideration of weighting will focus on the A-weighting and C-weighting of noise levels and describe how they act in a complementary manner to best reflect the human perception of loudness. Methods of summation will describe the time averaging of intensity metrics to derive quantities such as sound exposure level (SEL), equivalent sound level (LEQ), peak level, and time-above threshold metrics. Procedures for analyzing the spectral content of noise will be discussed, including consideration of octave and one-third octave band analysis, and the relationship between spectral characteristics of noise and human response will be considered.

Applications of Noise Analysis

The application of psychoacoustic methods and metrics to real world issues of industrial/occupational noise exposure and residential noise exposure will be considered through lecture and class discussion. Discussion of industrial/occupational noise exposure will describe exposure limits and standards for occupational noise exposure, the potential for hearing loss, and the maintenance of records in workplace hearing conservation programs. Discussion will also consider the potential impact of noise in the workplace on communications effectiveness and task performance. Consideration of residential noise exposure will discuss various environmental noise sources such as aircraft, trains, highways, powerplants, and industrial facilities and the assessment of their impact on affected communities. Various computer models of noise propagation and noise impact analysis will be discussed, and the use of these modeling tools for design and planning of workplaces and communities will be considered. Finally, discussion will focus on a consideration of noise mitigation techniques including mitigation of noise at the source, in the transmission path, and at the receiver's location. Passive methods such as baffling, noise barriers, and ear plugs and muffs will be used to demonstrate how noise can be attenuated at any of these three locations. Similarly, the principle of active noise cancellation, and the use of source based active noise reduction (ANR) devices, transmission based ANR, and receiver based ANR device such as ANR headsets will be discussed. Finally, a discussion of worker and public education and the implementation of hearing conservation programs will be discussed as potential mitigation alternatives. Classroom exercises will engage the participants in small group discussions to consider and decide on appropriate methods and metrics to analyze existing noise problems, propose various mitigation alternatives, and determine which alternative should be adopted for implementation.

Auditory Displays

The application of psychoacoustic methods and human factors principles to the design and integration of auditory displays will be considered. Discussion will focus on the advantages and disadvantages of using auditory presentations and the environmental and task factors to be considered in determining whether auditory display presentations should be used. Factors limiting the number and use of auditory displays such as the information load placed upon the auditory channel and discriminability of the auditory display signal in the specific task environment will also be considered. Finally, the emerging technology of spatial auditory displays used to create virtual localized sounds and its potential application for auditory displays will be discussed. Class exercises will engage participants in small group discussions of hypothetical scenarios that will allow the participants to gain experience in evaluating methods of auditory display presentation in a variety of complex systems and work environments.

Class Exercises

Classroom exercises will consist of discussion and group problem solving. To learn the skills required to compute acoustic metrics, the group will complete basic calculations of acoustic parameters. Class discussions will focus on the application of psychoacoustic methods to set up a simple study to test the human perception of noise. Classroom discussion and problem solving in the areas of applied psychoacoustics will use hypothetical scenarios to engage the class in exercises to apply the methods and metrics explained in classroom lectures to address potential real world psychoacoustic problems. For example, participants will be given a hypothetical scenario of an industrial facility with high noise levels where there is a need to protect workers from potentially dangerous noise levels and maintain compliance with Occupational Safety and Health Administration (OSHA) guidelines and exposure limits and there is also a need to maintain clear communications among workers for team coordination and safety in the facility. Participants will be asked to engage in a class exercise to consider and decide on appropriate methods and metrics to analyze the problem and propose various mitigation alternatives and determine which alternative should be adopted for implementation. To demonstrate the skills of using psychophysical principles in the evaluation, design, and integration of auditory displays, participants will be divided into small groups of approximately four individuals and will engage in exercises to evaluate the appropriateness of various methods of auditory presentation (e.g., tones, speech, spatial auditory displays) in complex systems and make critical decisions to improve or replace the current auditory displays in an existing system such as an aircraft cockpit.

The Interactive Sound Information System (ISIS). An integral part of the class presentations will consist of sound demonstrations played on the US Air Force's Interactive Sound Information System (ISIS). ISIS is a multimedia system for recreating high quality sound recordings at appropriate levels (i.e., as they would be heard in the real world) and integrating them into multimedia presentations to explain various topics in acoustics. The ISIS system was originally developed by David Dubbink Associates under contract to Armstrong Laboratory for educating Air Force planners, pilots, civil engineers, and the general public about noise created by Air Force operations and to recreate the noise generated by aircraft flights. The system is easily modified to perform a variety of functions to teach fundamental characteristics of sound and general principles of acoustics and psychoacoustics. The backbone of ISIS is a multimedia authoring tool and multimedia scripting language that allows the presentation developer to integrate full motion digital movies taken from video tape, film, or computer generated images with high fidelity digital audio reproductions of sound recordings. The use of the ISIS system will provide participants will high quality simulations of environmental sounds coupled with multimedia explanations using graphics and video presentations thereby allowing a better understanding of acoustic phenomena. The ISIS system will also allow participants to evaluate first hand the potential benefit of noise mitigation alternatives such as attenuation due to hearing protectors or sound barriers.

Sound Basics :

A PRIMER IN PSYCHOACOUSTICS

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Notes :

THE INSTRUCTOR

Bart Elias

Bart Elias is a Research Psychologist with the USAF Armstrong Laboratory, Noise Effects Branch at Wright-Patterson AFB, Ohio. Bart's interests include psychoacoustics, visual perception and the design and integration of auditory and visual displays in aviation and aerospace systems. Bart graduated from Franklin and Marshall College in Lancaster, PA in 1989 where he majored in Psychology. He received his M.S. in 1991 and his Ph.D. in 1994, both from Georgia Tech. His doctoral dissertation examined the use of dynamic spatial auditory cues for visual target acquisition. Currently, Bart is working on research programs to address the effects of environmental noise on outdoor recreationalists, and the effects of noise on speech patterns.

Notes :

THE STUDENTS

- Are interested in psychoacoustics
- Consult on industrial noise problems
- Consult on environmental noise problems
- Manage or consult on hearing conservation programs and evaluate occupational noise exposure
- Analyze speech intelligibility in noisy environments
- Design auditory displays

Who you are
Where you work/ what you do
Interest in taking this workshop

Notes :

GOALS

- Learn basic concepts in acoustics
- Learn basic anatomy and function of auditory system
- Learn basic psychoacoustic methods
- Apply knowledge to applied psychoacoustics problems:
  - Industrial/Occupational Noise Exposure
  - Hearing Conservation Programs
  - Speech and Task Interference
  - Residential Noise Exposure
  - Noise Mitigation
  - Design of Auditory Displays

Notes :

WHAT IS SOUND?

Webster's Collegiate Dictionary:

1. the sensation perceived by the sense of hearing

   stresses the importance of a receiver
   however, the receiver need not be human or even animate (Psychoacoustics: Study of the perception of sound by humans)
   - perceptual description of sound

2. mechanical radiant energy that is transmitted by longitudinal pressure waves in air (or other material medium) and is the objective cause of hearing.

   describes the properties of the ***source*** *(mechanical) and the* ***transmission medium*** *(air, water, etc.)*
   - physical description of sound

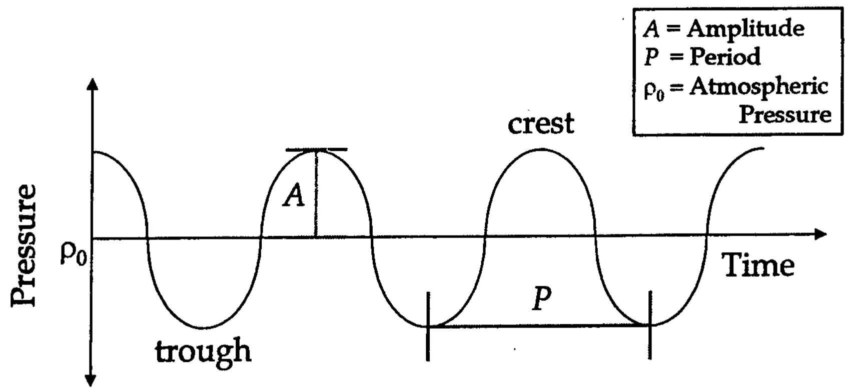
Notes :

ELEMENTS OF SOUND

- THE SOUND SOURCE
- THE TRANSMISSION MEDIUM
- THE RECEIVER

Notes :

THE SOUND SOURCE



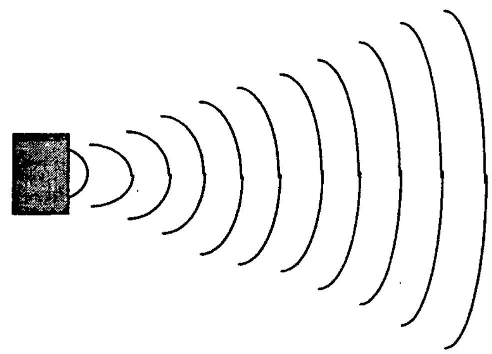
Frequency (f) = 1/Period

- measured in cycles per second
- Hertz (abbreviated Hz)

Notes :

THE SOUND SOURCE

The sound wave propogates from its source in a radiating pattern.



Notes :

SOUND SOURCE DESCRIPTORS

- SPEED
- FREQUENCY
- WAVELENGTH
- PHASE
- INTENSITY

Notes :

THE SPEED OF SOUND

- function of the transmission medium
- function of the temperature
  (speed increases with temperature)
- function of humidity
  (speed increases with humidity)

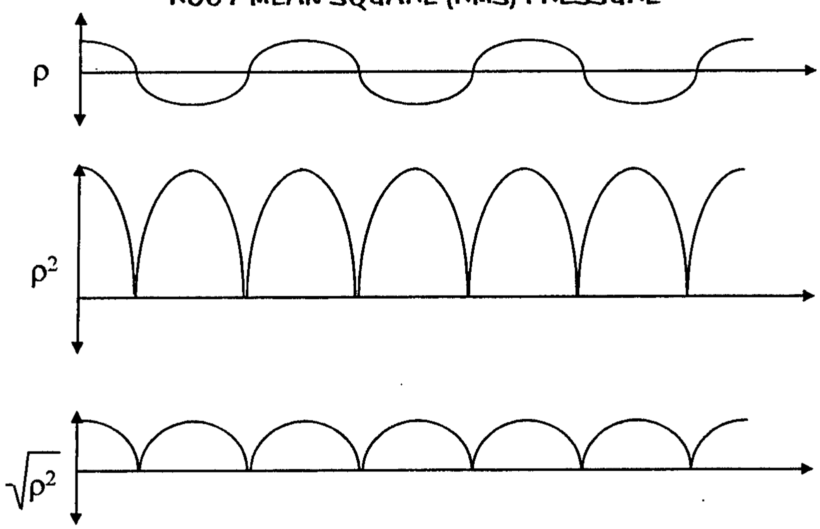
	meters per second	miles per hour
Air*	331	741
Oxygen*	316	707
Helium*	965	2158
Hydrogen*	1284	2871
Water (0^0 C)	1402	3135
Water (20^0 C)	1482	3314
Water (50^0 C)	1543	3450

* at 0^0 C

Notes :

SOUND INTENSITY

ROOT MEAN SQUARE (RMS) PRESSURE



Notes :

SOUND INTENSITY

RMS Integration Times

Impulsive sound:	35 msec
Fast	1/8th second
Slow	1 second

POWER

Sound power is related to the sound pressure squared (ρ^2)

measured in Pascals (Pa)

Notes :

SOUND INTENSITY

1 Pascal (Pa) = 1 Newton per square meter (N/m^2)
= 0.00015 pounds per square inch (lbs/in^2)

<u>To put it in perspective,</u>

1 Standard Atmosphere
= 101,300 Pa
= 14.7 lbs/in^2

Threshold of hearing:
= 0.00002 Pa
= 0.000000003 lbs/in^2

Normal Speech
= 0.02 Pa
= 0.0000029 lbs/in^2

Threshold of Pain
= 200 Pa
= 0.029 lbs/in^2

Notes :

SOUND LEVEL

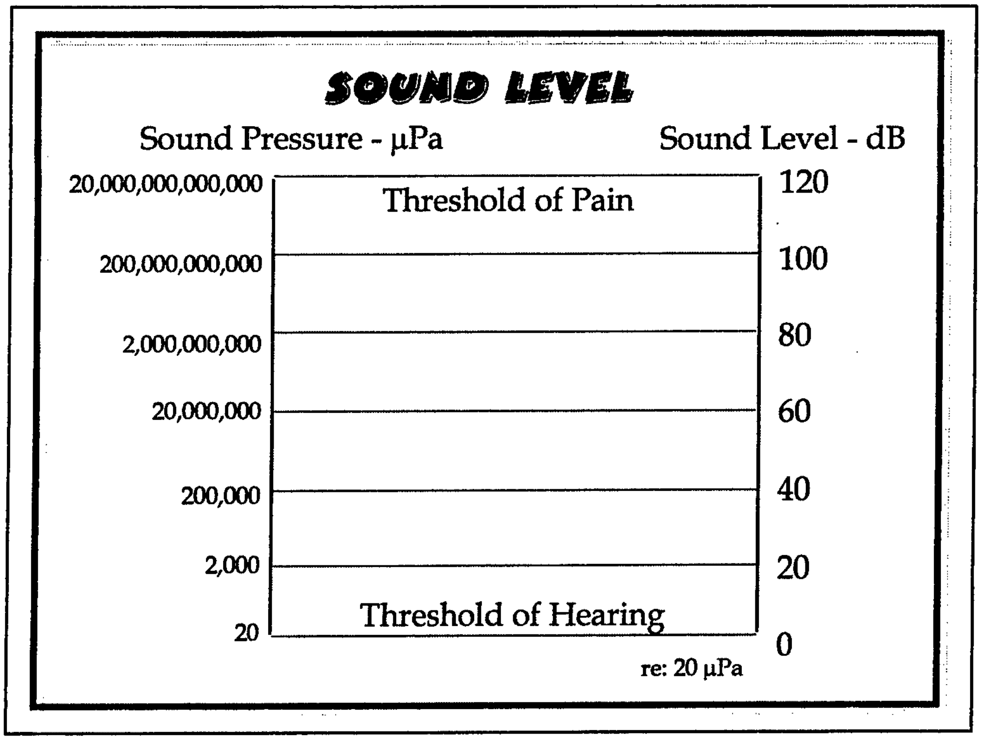
The Bel is a logarithmic ratio of any quantity (typically used for power-like quantities).

The Decibel is one tenth of a Bel.

$$L = 10 \text{ Log} \left[\frac{L}{L_{ref}} \right]$$

Used in describing noise because of the large range of pressures that humans are capable of hearing over.

Notes :


SOUND LEVEL
Sound Pressure - µPa
Sound Level - dB
20,000,000,000,000
200,000,000,000
2,000,000,000
20,000,000
200,000
2,000
20
Threshold of Pain
Threshold of Hearing
120
100
80
60
40
20
0
re: 20 µPa

Notes :

LET'S REVIEW LOGARITHMS!

$\log_b x$: The logarithm to the base b of x

$y = \log_b x$ and $x = b^y$

common bases:	10 (base often omitted)	common logarithm
	e (2.7182818)	natural logarithm

Properties of Logarithms:	Example:
$\log_b 1 = 0$	$\log_{10} 1 = 0$
$\log_b ac = \log_b a + \log_b c$	$\log_{10} 50 = 1.699$ (5*10)
$\log_b a/c = \log_b a - \log_b c$	$\log_{10} 3 = 0.47712$ (15/5)
$\log_b a^r = r\log_b a$	$\log_{10} 25 = 1.397$ (5^2)
$\log_b 1/c = -\log_b c$	$\log_b .25 = -0.602$ (4)

Notes :

COMPUTING SOUND LEVEL

Equation: $$L = 10 \text{ Log}\left[\frac{\rho^2_{rms}}{\rho^2_{ref}}\right] = 20 \text{ Log}\left[\frac{\rho_{rms}}{\rho_{ref}}\right]$$

ρ^2_{rms} = square of the rms pressure.
ρ^2_{ref} = squared reference pressure.

common values of ρ_{ref}:

Sound Pressure Level (SPL)
0.00002 Pascals (Pa) = 20 micro-Pascals (μPa)
(most common, generic threshold for human hearing)

Sensation Level (SL)
Psychoacoustically measured threshold for a given subject

Audio Standard
Maximum output of the system
Sound Level represent dB of attenuation

Notes :

COMPUTING SOUND LEVEL

Problem:

You have a very sensitive pressure gauge that reads out in lbs/in^2 attached to a microphone.
It records an event of 0.000042 lbs/in^2
How loud was the event in dB (re: 0.00002 Pa) ?

Given: $1\ lb/in^2 = 6711$ Pa

Calculations:

Answer:

Notes :

COMPUTING SOUND LEVEL

Answer:

	0.000042 lb/in^2
x	6892 Pa per lb/in^2
=	0.289464 Pa
	0.289464 Pa / 0.00002 Pa
=	14,473
	Log (14,473)
=	4.1605 .....
x	20
=	83.21 dB

Notes :

DECIBEL ADDITION

recall from our review of logarithms that
$\log_b a + \log_b c$ is not equivalent to $\log_b a + c$

so we cannot add dBs together to get cumulative sound levels.

Instead, $$L_{1+2} = 10 \text{ Log} \left[\frac{\rho^2_{(1)rms} + \rho^2_{(2)rms}}{\rho^2_{ref}} \right]$$

$$= 10 \text{ Log} \left(10^{L_1/10} + 10^{L_2/10}\right)$$

Similarly we can subtract unrelated sound levels:

$$L_{1-2} = 10 \text{ Log} \left(10^{L_1/10} - 10^{L_2/10}\right)$$

Notes :

DECIBEL ADDITION

To get a quick estimate (accurate within one dB)

if the difference between L_1 and L_2 is:	Add this to the greater of L_1 or L_2
0 to 1 dB	3 dB
2 to 3 dB	2 dB
4 to 9 dB	1 dB
> 10 dB	0 dB

Notes :

DECIBEL ADDITION

Problems (calculate and compare to approximation):

Two F-16s fly over your house in afterburner at 500 ft. You know that the sound level of one F-16 at that distance using afterburner is 122 dB. What is the sound level of this formation flyover?

A second generator is added to a power plant. The older, noiser model produced a continuous 98 dB at the control console workstation. According to the manufacturer, the newer quieter model will produce 90 dB at 25 ft, which is the distance to the control console. What is the expected noise exposure of the operator working at the control console?

Notes :

DECIBEL ADDITION

Answers :

$$10 \text{ Log} (10^{12.5} + 10^{12.5})$$

$$= \quad 10 \text{ Log} (10^{12.5} \times 2)$$

$$= \quad \underline{125.01 \text{ dB}}$$

difference = 0 dB, so +3dB = 122 + 3 = <u>125 dB</u>

$$10 \text{ Log} (10^{9.8} + 10^{9.0})$$

$$= \quad 98.63892 \text{ dB}$$

difference = 8 dB, so +1dB = 98 + 1 = <u>99 dB</u>

Notes :

DECIBEL ADDITION

Problems (calculate and compare to approximation):

In a noisy control room the ambient (background) level is 80 dB, a warning alarm goes off and a level of 86 dB is recorded at the operators station. What is the sound level of the warning alarm?

In a quiet community, the background noise measures 50 dB. When Joe runs his lawnmower, the sound level recorded in his neighbors backyard is 73 dB. How loud is Joes lawn-mower at the noise monitor's location?

Notes :

DECIBEL ADDITION

Answers :

$= \quad 10 \text{ Log } (10^{8.6} - 10^{8.0})$

$= \quad \underline{84.74 \text{ dB}}$

difference = 6dB, so -1dB 86-1 = <u>85 dB</u>

$= \quad 10 \text{ Log } (10^{7.3} - 10^{5.0})$

$= \quad \underline{72.98 \text{ dB}}$

difference = 23 dB, so -0dB 73 - 0 = <u>73 dB</u>

Notes :

MEASURING SOUND LEVELS

Sound Level Meter

Integration Time

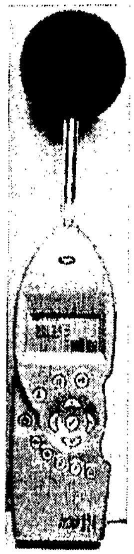
- Slow — 1 second
- Fast — 1/8th second

Weighting

- Unweighted
  All Frequencies Treated Equal
- A weighting
  Human AuditoryResponse
- C weighting
  Low Frequency

Notes :

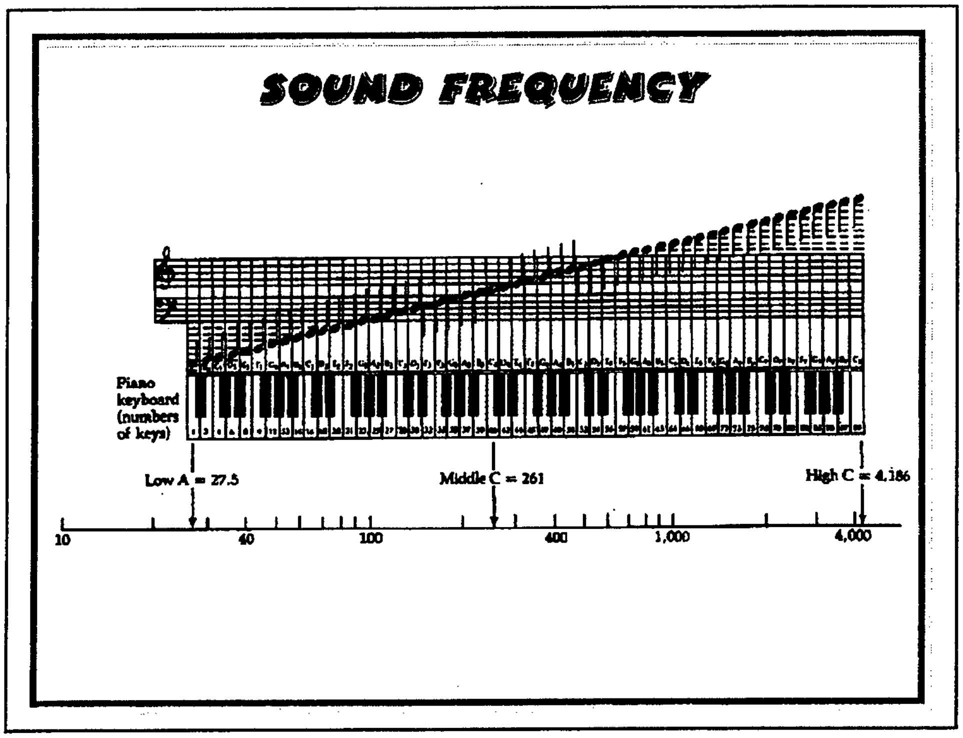
MEASURING SOUND LEVELS



Demonstration:

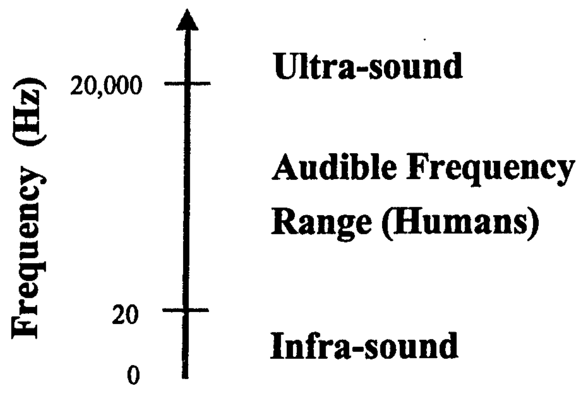
Measuring sound levels with a portable sound level meter.

Notes :


SOUND FREQUENCY
Piano keyboard (numbers of keys)
Low A = 27.5
Middle C = 261
High C = 4,186
10
40
100
400
1,000
4,000

Notes :

FREQUENCY RANGE



wavelength (λ): 52 feet @ 20 Hz
0.6 inches @ 20K Hz

Notes :

WAVELENGTH

Symbol: λ

Dependent on

- The *frequency* or *period* of interest
- The *speed* of sound

In general,

$\lambda = c/f$

c = 1036 ft/s (in air, dependent on atomospheric conditions

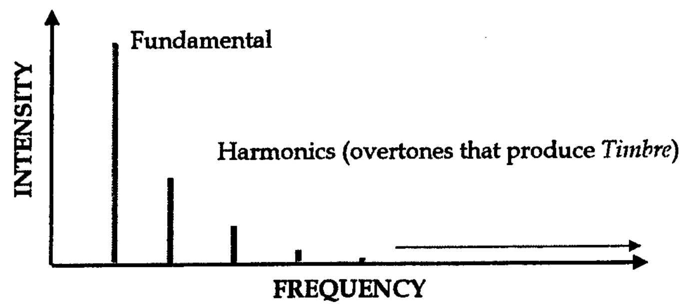
f = frequency

Problem: What is the wavelength of a 750 Hz pure tone ?

Notes :

THE FREQUENCY DOMAIN

Plot of Intensity as a function of frequency:

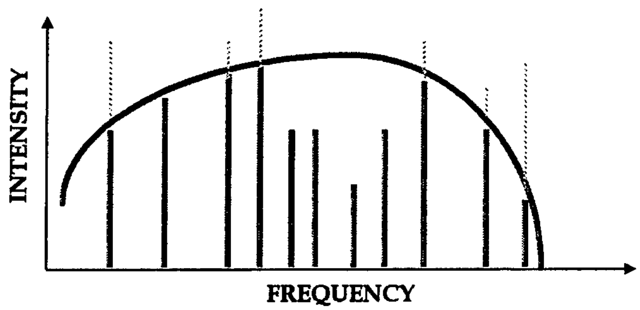


Fourier Principle: All complex waveforms are the sum of sinusoidal wave components. Sine waves are the simplest elements of a complex wave.

Square Wave: $f + 3f(1/3) + 5f(1/5) + 7f(1/7) + \ldots$

Notes :

MODULATION TRANSFER FUNCTIONS



<u>Everyday examples</u>:

- Stereo Systems
- Loud-speakers
- Microphones
- Your auditory system

Notes :

MEASURING FREQUENCY

- Frequency Counter
  Pure tones
- Full Spectral Analysis
  Analyzer - Fourier Transform (FFT)
- Octave Band Analysis
- One-Third Octave Band Analysis

Notes :

FREQUENCY BANDS

Constant percentage bandwidth

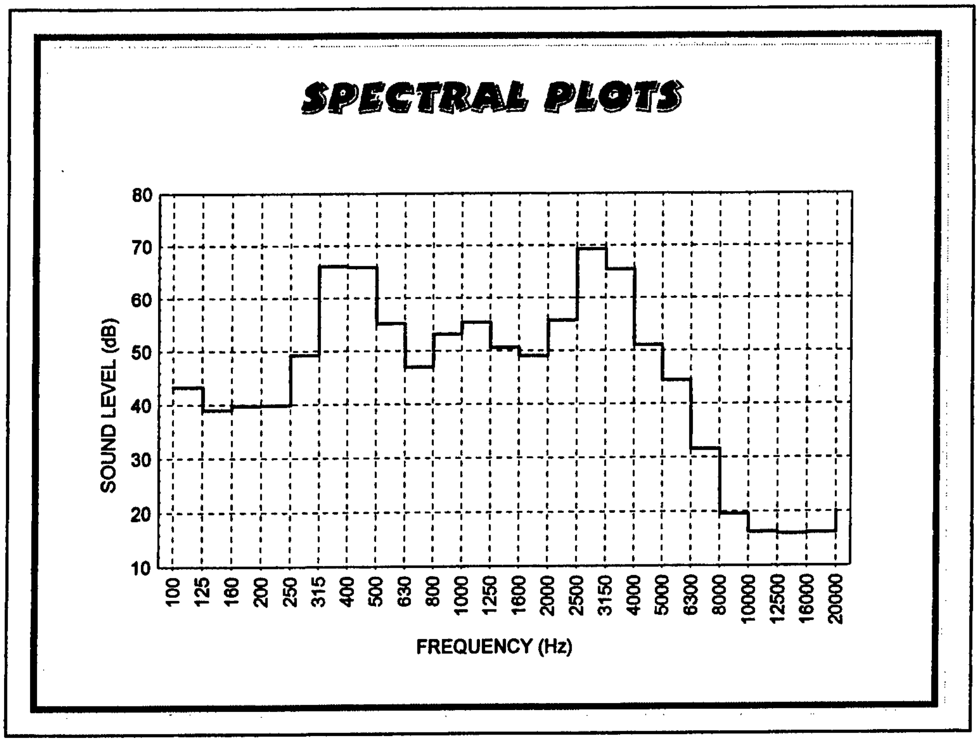
<u>Center Frequencies (Hz):</u>

Octave Bands
31.5 63 125 250 500 1000 2000 4000 8000 16000

One-Third Octave Bands

25 40 63 100 160 250 400 630 1000 1600 2500 4000 6300 10000 16000
31.5 50 80 125 200 315 500 800 1250 2000 3150 5000 8000 12500 20000

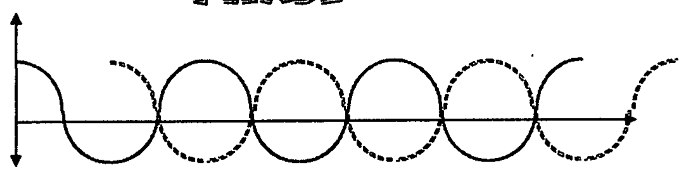
Notes :


SPECTRAL PLOTS
SOUND LEVEL (dB)
80
70
60
50
40
30
20
10
100
125
160
200
250
315
400
500
630
800
1000
1250
1600
2000
2500
3150
4000
5000
6300
8000
10000
12500
16000
20000
FREQUENCY (Hz)

Notes :

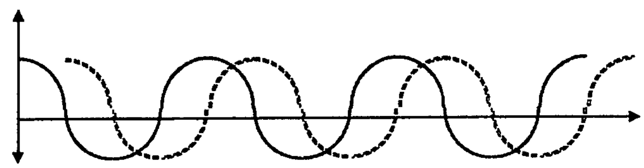
PHASE

180



Cancellation

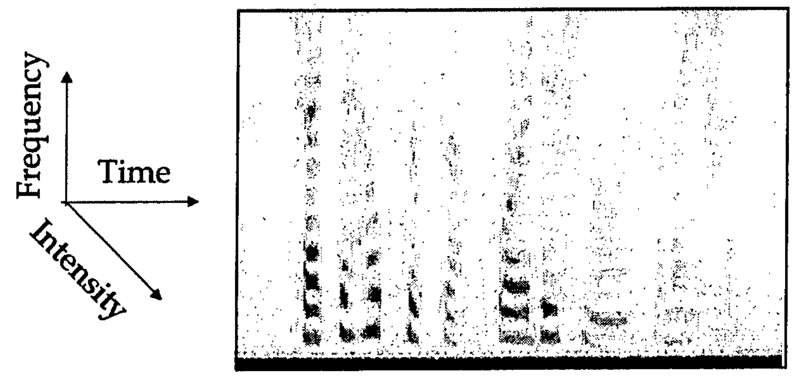
90



Multiple sources or Multiple receivers
e.g. active noise control, sound localization

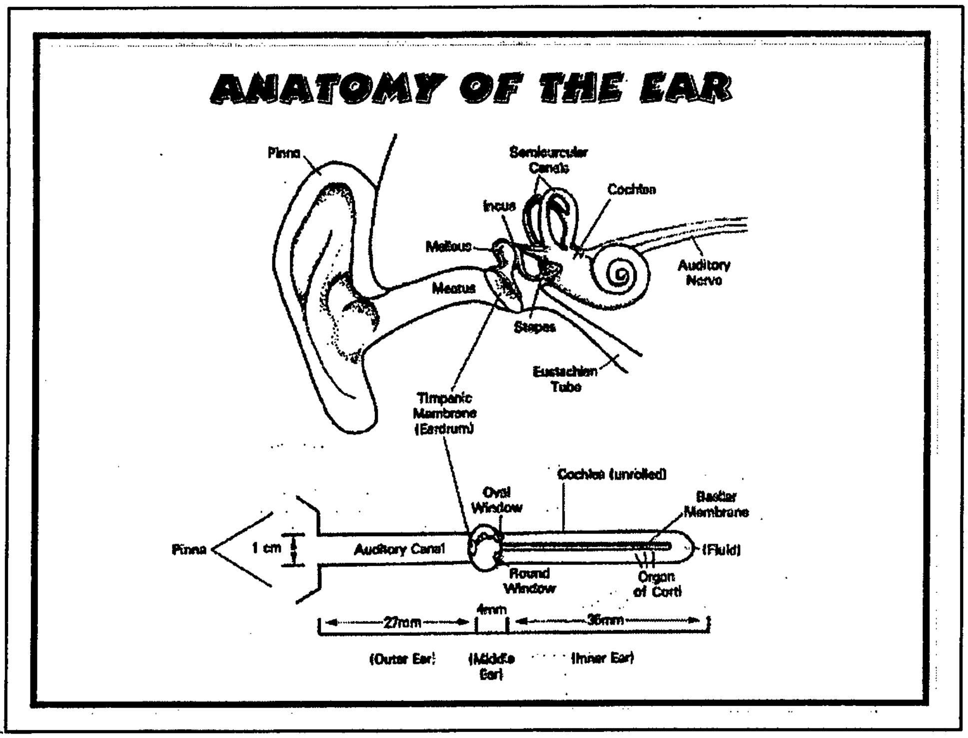
Notes :

SOUND SPECTOGRAMS



"Check the Help System for Additional Information"

Notes :


ANATOMY OF THE EAR
Pinna
Semicircular Canals
Cochlea
Incus
Malleus
Meatus
Auditory Nerve
Stapes
Eustachian Tube
Timpanic Membrane (Eardrum)
Cochlea (unrolled)
Oval Window
Basilar Membrane
Pinna
1 cm
Auditory Canal
(Fluid)
Round Window
Organ of Corti
27mm
4mm
35mm
(Outer Ear)
(Middle Ear)
(Inner Ear)

Notes :

PHYSIOLOGY OF THE EAR

Outer Ear
- Pinna
- Ear Canal — Resonant Freq. 2000 Hz

Inner Ear
- Tympanic Membrane
- Ossicles
  - Malleus -Hammer
  - Incus -Anvil
  - Stapes -Stirrup

- Cochlea - hearing
- Otoliths (semicircular canals)- vestibular
- Auditory Nerve

Notes :

FUNCTION OF THE EAR

- Outer Ear - Modifies sound for better localization
- Tympanic Membrane ⟶ Cochlea

  Change of Transmission Medium

  Air ⟶ Fluid

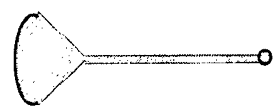
  Increases Power (Amplification)

  10-50 % greater

  Impedance: Ratio of the pressure to the volume displacement in a sound medium

  Need to decrease the volume

  Tympanic Membrane ⟶ Stapes



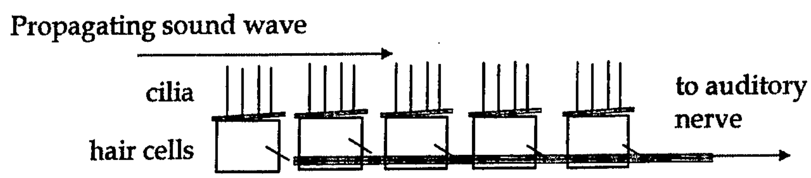
Notes :

FUNCTION OF THE EAR

- Cochlea (Inner Ear)
  - *Transduction* (transducer)

    Mechanical ⟶ Electro-chemical

    Cilia (on hair cells) - receptive cells



Notes :

FUNCTION OF THE EAR

Pitch (Frequency)

- Low frequency coded by frequency of neural firing (< 1000 Hz) - rate of cilia displacements
- High frequency coded by pattern/location of cells that are firing (> 5000 Hz) - determined by the shape of the cochlea
- Both types of coding are used between 1000 and 5000 Hz

Loudness (Intensity)

- Coded by rate of firing (action potential) - magnitude of cilia displacements

Notes :

AUDITORY CORTEX

Auditory Nerve ⟶
Primary Auditory Cortex

Tonotopic map

columnar *arrangement of neurons* grouped by frequency response

Temporal Lobe

Important for:

- discriminating tonal patterns, but not tones
- discriminating timing/duration of sounds
- localizing sounds

Outputs to speech and language cortical areas

Notes :

METHODS OF PSYCHOACOUSTICS

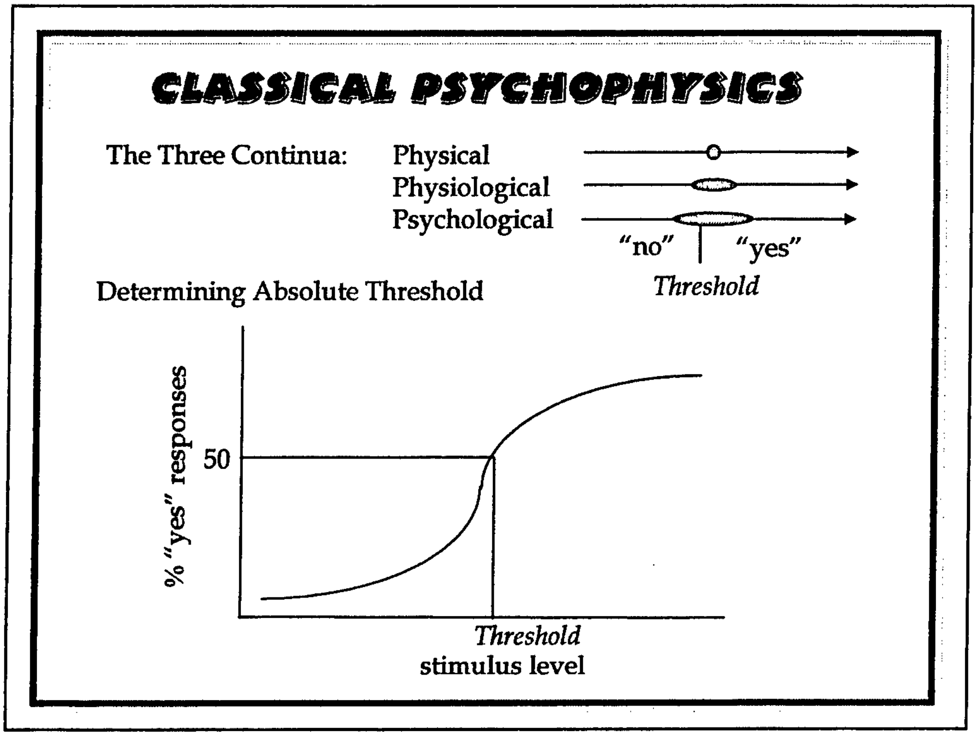
- Determining Thresholds &
  Determining Just Noticeable Differences (JNDs)

  - Classical Psychophysics
    - Method of Limits
    - Method of Constant Stimuli
    - Method of Adjustment

  - Signal Detection Theory

- Comparing Sounds (Stimuli)
  - Scaling Procedures

Notes :


CLASSICAL PSYCHOPHYSICS
The Three Continua:
Physical
Physiological
Psychological
"no"
"yes"
Threshold
Determining Absolute Threshold
% "yes" responses
50
Threshold
stimulus level

Notes :

CLASSICAL PSYCHOPHYSICS

Determining Absolute Threshold:

Method of Limits:
- ordered presentations (staircase)

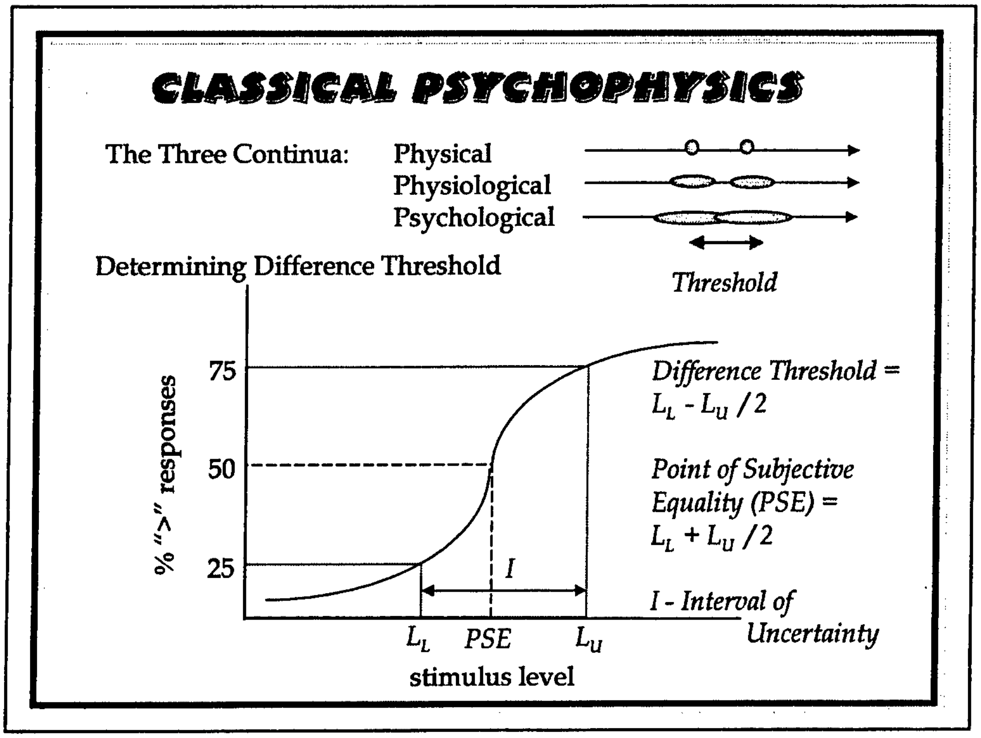
ascending trials	T_a
descending trials	T_d
Absolute Threshold	$= T_a + T_d / 2$

Method of Constant Stimuli
- random order presentations

Method of Adjustment
- subject adjusts stimulus levels

ascending trials	T_a
descending trials	T_d
Absolute Threshold	$= T_a + T_d / 2$

Notes :


CLASSICAL PSYCHOPHYSICS
The Three Continua:
Physical
Physiological
Psychological
Threshold
Determining Difference Threshold
% ">" responses
75
50
25
L_L
PSE
L_U
stimulus level
I
Difference Threshold =
$L_L - L_U / 2$
Point of Subjective Equality (PSE) =
$L_L + L_U / 2$
I - Interval of Uncertainty

Notes :

CLASSICAL PSYCHOPHYSICS

Determining Difference Thresholds:

Method of Limits:

- 3 responses: > < = standard stimulus

trials:

1/2 standard stimulus - variable stimulus
1/2 variable stimulus - standard stimulus
1/2 ascending trials
1/2 descending trials

limen: L_U *(upper threshold or limen)* $= A_U + D_U / 2$

= to >

L_L *(lower threshold or limen)* $= A_L + D_L / 2$

= to <

where *A* denotes Ascending thresholds
D denotes Descending thresholds

L_D *(difference threshold)* $= L_L - L_U / 2$

Point of Subjective Equality (PSE) $= L_L + L_U / 2$

Notes :

CLASSICAL PSYCHOPHYSICS

Determining Difference Thresholds (continued):

Method of Constant Stimuli:

- 2 responses: > < standard stimulus

trials:

1/2	standard stimulus - variable stimulus
1/2	variable stimulus - standard stimulus
1/2	ascending trials
1/2	descending trials

Method of Adjustment

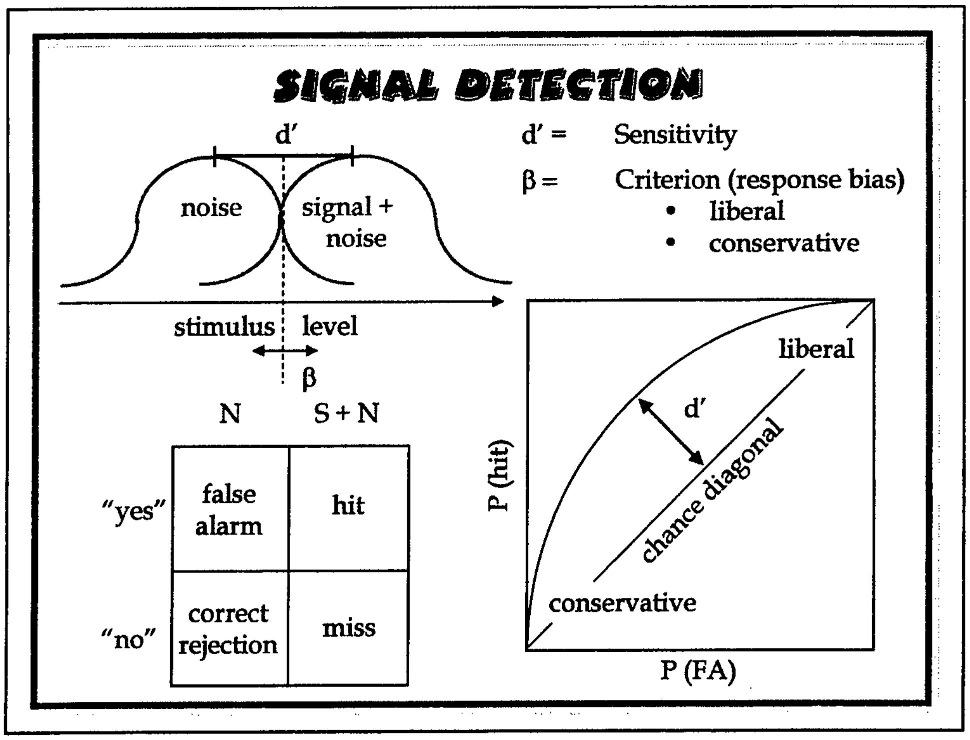
- subject control
- adjust to perceived equality with standard

trials:

1/2	ascending trials
1/2	descending trials

constant error = PSE - standard stimulus

Notes :


SIGNAL DETECTION
d′
noise
signal + noise
stimulus level
β
N
S + N
"yes"
"no"
false alarm
hit
correct rejection
miss
d′ = Sensitivity
β = Criterion (response bias)
• liberal
• conservative
liberal
d′
chance diagonal
conservative
P (hit)
P (FA)

Notes :

PSYCHOPHYSICAL SCALING

Weber's Law: $\Delta S/S = k$

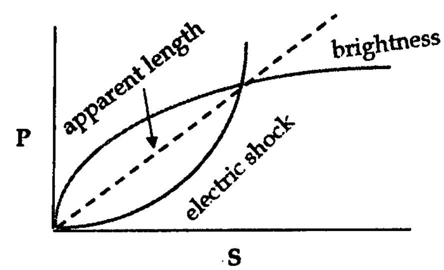
$\Delta S = kS$ (just noticable difference is a constant proportion of the standard)

Fechner's Law: $P = k \log S$

Steven's Power Law $P = kS^n$

Magnitude Estimation (Scaling)

- modulus (standard) : assign a value (e.g., 50)
  variable stimuli:compare to modulus on a rating scale (e.g., 0 to 100)
- modulus free procedure: rate variable stimuli on a scale



Notes :

PSYCHOACOUSTIC STIMULI

Pure Tones:	Sinusoidal wave of a single frequency
White Noise:	Broadband noise where the energy level is uniform over the audible frequency spectra
Pink Noise:	Broadband noise whose spectral level decreases with increasing frequency to yield constant energy per octave band (Note: Octave bands widen with increasing frequency)
Filtered Noise:	Filtered by Octave Band, 1/3 Octave Band
Duration:	Continuous or Short Bursts Bursts: Onset Rate, Decay
Waveform:	Envelopes, Carrier Frequencies (Modulation)
Impulses	Presentations with rapid onset (>35 msec to peak) and Short duration (<500 msec)
Click Trains	Series of short, low intensity impulses (clicks) used especially in spatial hearing

Notes :

PSYCHOPHYSICAL METRICS OF PERCEIVED LOUDNESS

Phon : A measure of loudness equivalent judged equally as loud as the decibel level of a 1000 Hz pure tone

Sone : One *sone* is equivalent to the *loudness* of a 1000 Hz pure tone presented at 40 dB. A sound judged twice as loud has a loudness of 2 *sones*, three times as loud - three *sones* , ...
1 Sone = 40 Phons   +1 Sone = +10 Phons

Noy : One *noy* is equivalent to the *annoyance* of a 1000 Hz pure tone presented at 40 dB

Perceived Noise Level (PNdB) = $40 + 33.3 \log N$
where N = perceived noisiness in *noys* (broadband noise)

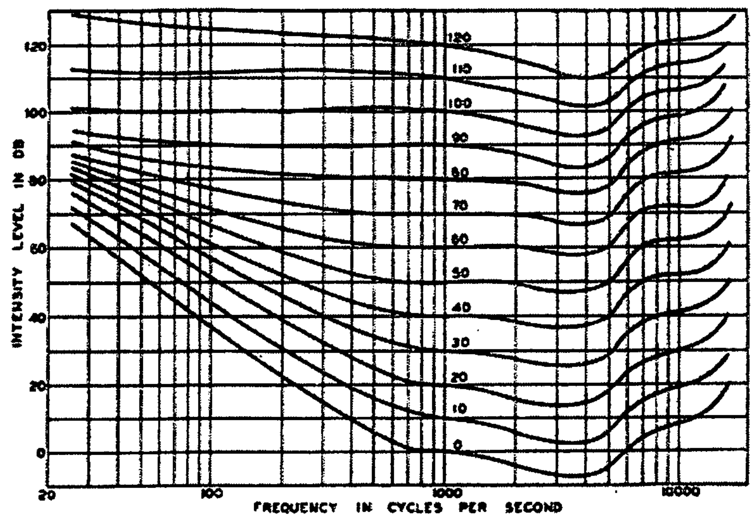
Effective Perceived Noise Level (EPNdB or EPNL) : PNdB corrected for tones (aircraft noise)

Mark VII Sones : Perceived loudness relative to sound of 1/3 octave band noise centered at 3150 Hz
1 Mark VII sone = 32 PLdB, +1 Mark VII sone = +9 PNdB

Notes :

EQUAL LOUDNESS CONTOURS

Fletcher & Munson (1933)

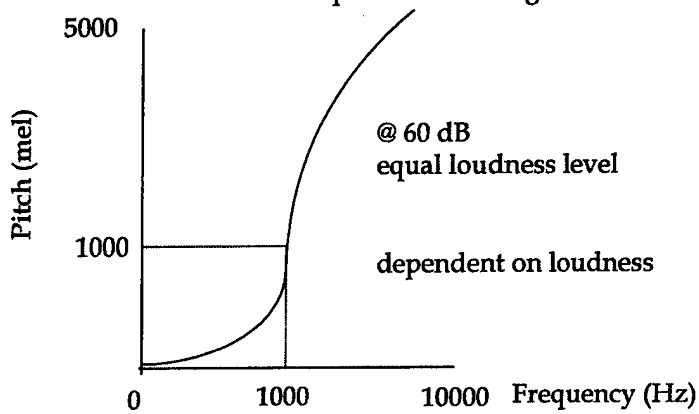


Notes :

PITCH PERCEPTION

Pitch: psychological correlate to frequency

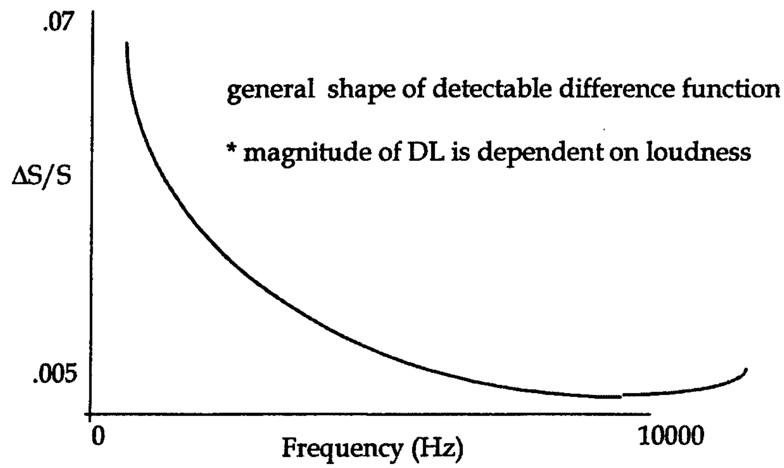
mel: (from melody)
- scale unit of pitch
- doubling of *mel* corresponds to a pitch twice as high



Notes :

PITCH PERCEPTION

Difference limen (thresholds):



Notes :

PITCH PERCEPTION

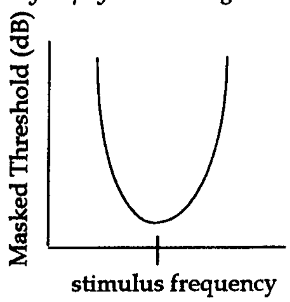
Frequency selectivity / frequency resolution:

The ability to discriminate/isolate distinct tones presented *simultaneously.*

critical bands: non-linear (i.e., level dependent) frequency filters in the auditory system

masking: the inability to detect a tonal signal due to noise in the signals critical band

Psychophysical Tuning Curves (PTCs):



narrow band noise levels required to mask a tonal signal - frequency dependent (widen with increasing frequency

Notes :

PITCH PERCEPTION

Tonal Patterns :

Harmony: consonance or dissonance
Harmonics
Musical Scales octaves
fifths
thirds
twelfths
Chords

Timbre Overtones

Complex waveforms

Notes :

TEMPORAL PATTERN PERCEPTION

- Temporal Integration
  - time required to detect a signal
  - time-intensity trade-off
    - signal level at threshold increases
    - with decreasing signal duration
    - up to 200 msec for complex tones
    - up to 500 msec for pure tones
- Temporal Acuity
  - Temporal Order Detection
  - Phase Detection
  - Temporal Gap Detection
  - Amplitude Modulation Detection
    - much shorter than temporal integration time
      - 2 msec (up to 30 msec)
    - stable over a broad range of stimulus conditions
  - Temporal Asynchrony
    - harmonic more easily detected than non-harmonic

Notes :

SPATIAL HEARING

Spatial Hearing refers to the ability to localize the position and distance of a sound source:

Parameters:

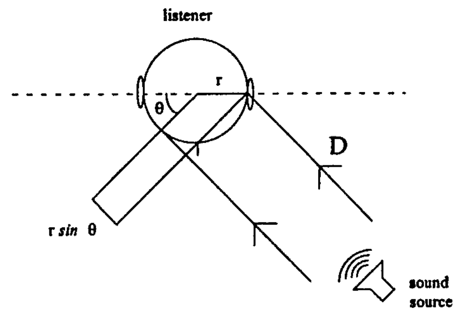
- Elevation
- Azimuth (Degrees Left or Right)
- Distance

Notes :

SPATIAL HEARING

Cues for Localizing Sounds:

- Interaural Time Differences (ITDs)
  differences in arrival time or phase or the sound source between the two ears



Notes :

SPATIAL HEARING

Cues for Localizing Sounds:

- Interaural Time Differences (ITDs)
  differences in arrival time or phase or the sound source between the two ears

- Interaural Intensity Differences (IIDs)
  differences in sound intensity between the two ears

Arise due to Interaural Paths Distances (*d*)

$$d = r\,\theta + r \sin \theta$$

$\theta = \pi$ – incedence angle, r = radius of head

Notes :

SPATIAL HEARING

- Interaural Time Differences (ITDs)

  ITD = d/c

  where d = interaural path distance
  c = speed of sound

  Example: d= .75 ft, c=1,086 ft/s ITD= 0.69 msec

- Interaural Intensity Differences (IIDs)

  IID = 20 log (D+d/D)

  where D = distance from sound source to nearer ear
  d = interaural path distance

  Example: d= .75 ft, D=20 ft IID= 0.32 dB

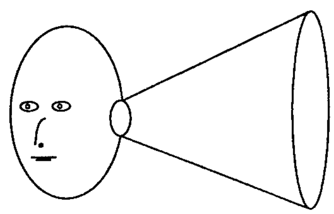
Notes :

SPATIAL HEARING

Weaknesses: Interaural Paths Distances *(d)*

- assume the head is perfectly sperical
- do not account for the effects of shadowing and attenuation by the head.
- do not account for the *pinna*.

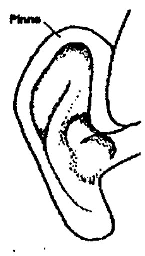
An Auditory *Cone of Confusion* exists and it describes a region in space in which all identical sound sources within the cone will produce identical ITDs and IIDs.



Notes :

SPATIAL HEARING

Effects of the Pinna (Outer Ear)



Folds (convolutions) of the pinna act as a *comb filter* creating delayed replications of the incoming sound signal.

Greatly improves localization abilities, especially judgments of vertical position

Effects of the Head and Upper Torso

Head creates a shadow that greatly increases IIDs - especially at high frequencies where measured IIDs can be as great as 20 dB

Upper Torso causes reflections

Notes :

SPATIAL HEARING

Head Related Transfer Function (HRTFs) : digital representations of the transformation of the sound signal caused by the anatomy of the head, upper torso and pinna.

Transformation of the signal is the difference between the original output signal and the signal recorded at the location of the tympanic membrane.

Process of determining the HRTF is called *convolution.*

Convolution: is the multiplication of a sound spectra and a modulation transfer function.

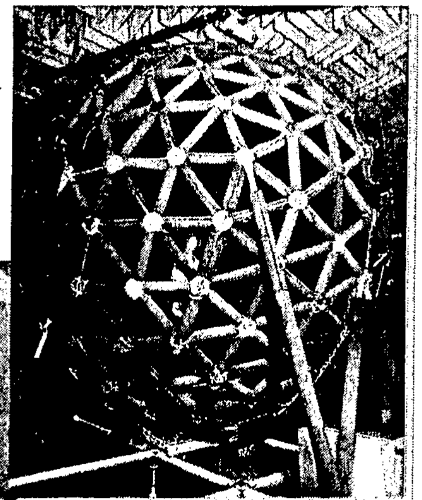
Used for generating 3-D audio displays. Produces *localized* sounds as opposed to stereo headphones which produce *lateralized* sounds.

Notes :

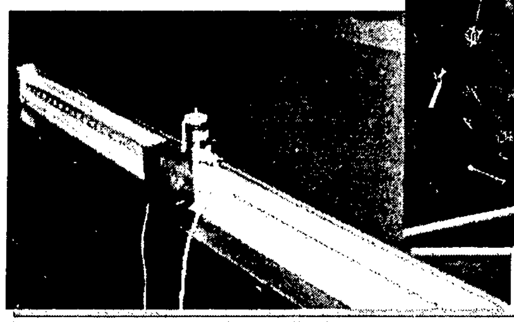
SPATIAL HEARING

Research Tools

Speaker Array



Moving Speaker



Notes :

SPATIAL HEARING

Psychoacoustic Methods and Metrics:

Pointing

Dependent variables:

- *correlation* between reported and actual sound locations
- accuracy (error magnitude)
- reliability (error variance)

Minimum Audible Angle (MAA)

Psychophysically determine the smallest angular separation in sound sources that can be reliably detected

Minimum Audible Movement Angle (MAMA)

Psychophysically determine the smallest angular displacement of the sound source whose direction can be reliably detected

Notes :

PERCEIVING DISTANCE

Cues for Distance:

- Intensity Cues

  Sound Level follows an inverse square function of distance

  $$\frac{1}{R}\ loss\ /\ gain\ (dB) = 20\ \log_{10} \frac{R}{R_0}$$

  where R is the new distance, and R_0 is the referent distance

  Example:
  A sound that measures 80 dB at 100 ft will measure 86 dB at 50 ft
  74 dB at 200 ft

Notes :

PERCEIVING DISTANCE

Cues for Distance (continued):

- Spectral Absorption Cues
  High frequency components undergo greater signal loss, so distant sound have greater low frequency content.
- Reverberation Cues
  Reflections of the sound off walls, ceilings and other structures and objects in the listening environment can give cues to distance and location.

  Reverberation time: Time required for a sound level to decrease by 60 dB

Notes :

PERCEIVING DISTANCE

Reverberation Times

	Carnegie Hall, New York	Symphony Hall, Boston
125 Hz	1.8 s	2.2s
250 Hz	1.8 s	2.0s
500 Hz	1.8s	1.8s
1000 Hz	1.6s	1.8s
2000 Hz	1.6s	1.7s
4000 Hz	1.4s	1.5s

from Kinsler, et al. (1982)

Notes :

PERCEIVING MOTION

Cues for Motion:

- Changes in localization and distance cues of sound signal over time.
- Doppler Shift: the relative increase or decrease in frequency of a sound that results from the relative motion of the sound source and/or the receiver - due to *compression* and *rarefaction* of the sound wave

$$\Delta f = \frac{u + v}{c} f$$

Δf = change in frequency
u = speed of receiver
v = speed of source
c = speed of sound

Notes :

PERCEIVING MOTION

Problem:

You are riding a bike at 10 mph, heading north along a road that parallels train tracks. A south-bound train traveling at 60 mph blows its horn. The horn is dominated by a 800 Hz tone. What is the change in frequency at 800 Hz? What is the resulting frequencies as it approaches and as it recedes?

The speed of sound for that day is 760 mph

Notes :

PERCEIVING MOTION

Answer:

$u = 10$

$v = 60$

$c = 760$

$(10 + 60)/ 760 = 0.0921$ ....

x 800 Hz

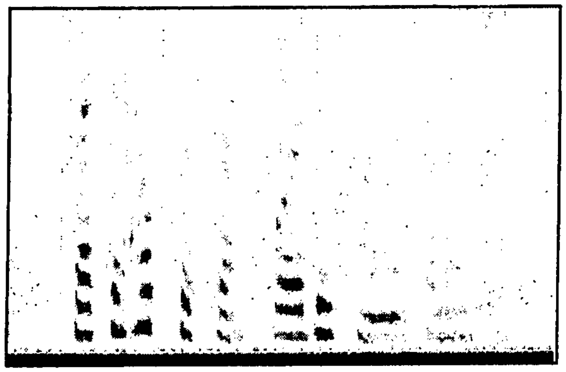
= 73.68 Hz

800 + 73.68 = <u>873.68 Hz</u>

800 - 73.68 = <u>726.32 Hz</u>

Notes :

SPEECH PERCEPTION



"Check the Help System for Additional Information"

Phonemes : building blocks of speech, shortest segment of speech which if changed would change the meaning of a word

Notes :

ENGLISH LANGUAGE PHONEMES

Consonants

p	pull	s	sip
b	bull	z	zip
m	man	r	rip
w	will	Š	should
f	fill	z	pleasure
v	vet	c	chop
θ	thigh	j	gyp
	thy	y	yip
t	tie	k	kale
d	die	g	gale
n	near	h	hail
l	lear	n	sing

Vowels

i	heed
I	hid
e	bait
ε	head
æ	had
u	who'd
U	put
L	but
o	boat
	bought
a	hot
	sofa
i	many

Notes :

PERCEIVING PHONEMES

formats :	steady frequency bands vowels
formant transitions:	rapid frequency shifts consonants dependent on vowel the precedes or follows
articulation pattern:	stop fricatives voicing unique for each phoneme

Applied Topic: Speech Intelligibility and Speech Interference

Notes :

BREAK

Notes :

APPLIED PSYCHOACOUSTICS

Noise Measurements

Occupational Noise Exposure

Residential Noise Exposure

Noise Modeling

Noise Mitigation

Auditory Displays

Product Sound Quality

Notes :

WEIGHTING OF SOUND LEVELS

A weighting (dB(A))

Frequency dependent adjustments (weighting) of sound level to approximate the sensitivity of the human auditory system

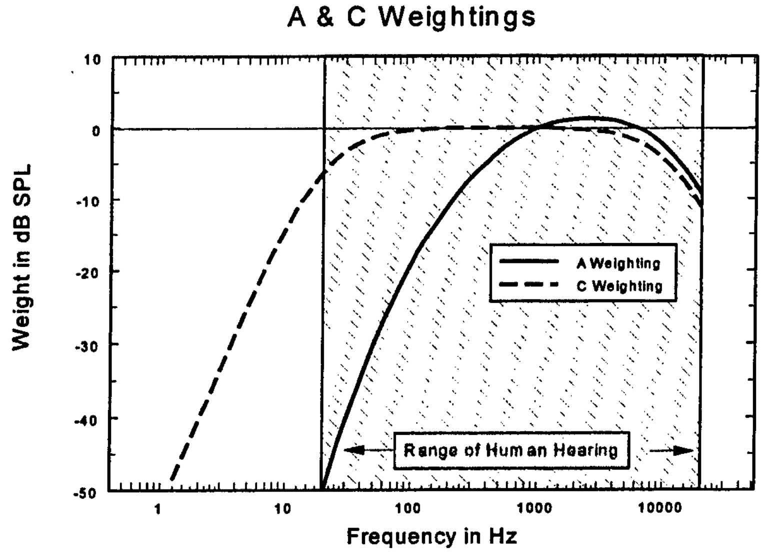
Based on equal-loudness countours

C weighting (dB(C))

Frequency dependent adjustments (weighting) of sound level that retain greater power in the lower frequency ranges (below 20 Hz), to account for building resonances which lead to rattling

Notes :

WEIGHTING



Notes :

NOISE DESCRIPTORS

Sound is time varying, so we need to sum or average the energy and normalize these numbers to provide tractable metrics of sound exposure

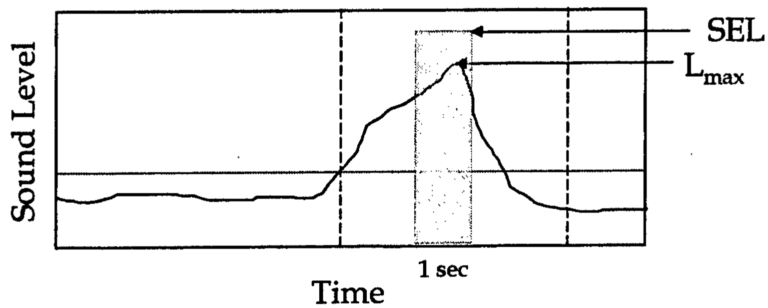
- Short Term (Single Event) Metrics
  - Maximum Sound Level - L_{max}
  - Sound Exposure Level - SEL
- Long Term (Cumulative) Metrics
  - Equivalent Sound Level - L_{eq}
  - Exceedance Percentile Sound Level - L_n
  - Time Above Threshold

Psychophysical descriptors: Phons, Sones, Noys, etc.
(Frequency dependent)

Notes :

NOISE DESCRIPTORS

- L_{max}
  - Maximum sound level received over a period
- Sound Exposure Level (SEL)
  Total sound power received during a given event normalized to a one second time period



Notes :

NOISE DESCRIPTORS

Equivalent Sound Level (L_{eq})

The level of continuous sound over a given period that would deliver the same amount of energy as the actual time varying sound exposure.

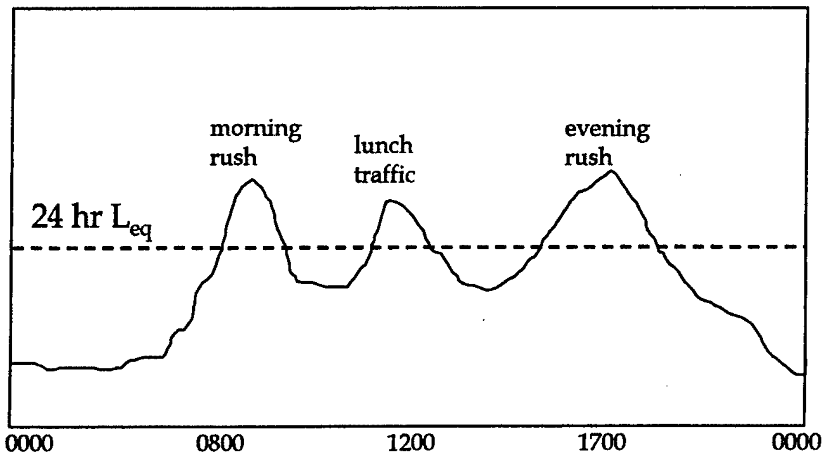
Multiple equal length time periods (N):

$$L_{eq} = 10 \operatorname{Log} \frac{1}{N} \sum_{i=1}^{N} 10^{L_i/10}$$

Notes :

NOISE DESCRIPTORS

Equivalent Sound Level (L_{eq})



Notes :

NOISE DESCRIPTORS

Relationship Between LEQ and SEL

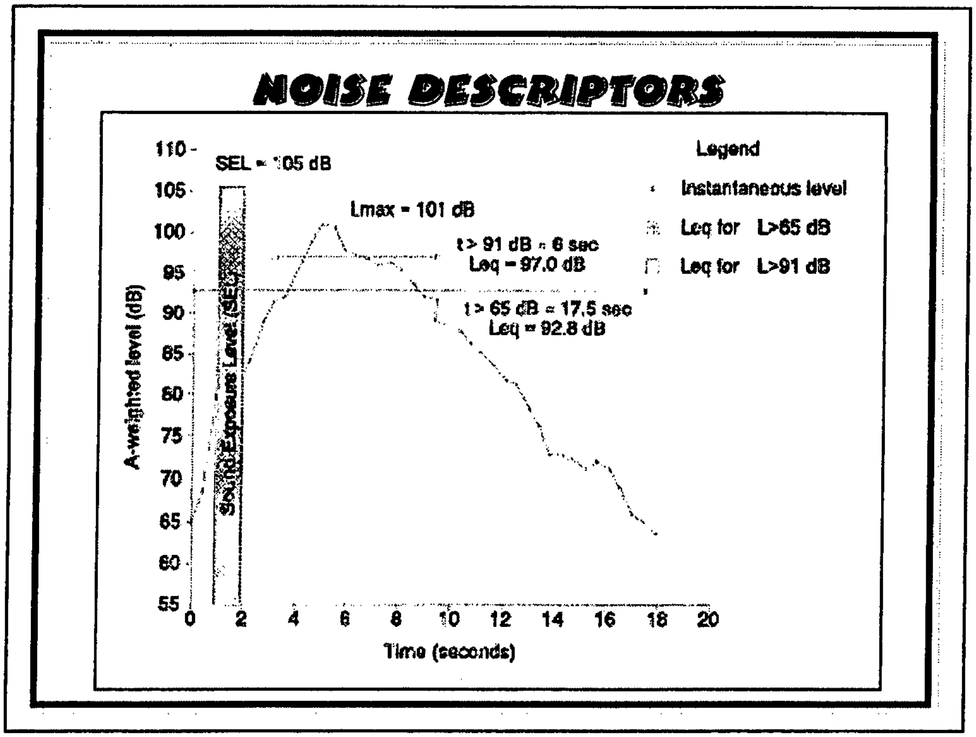
$$L_{eq(\mathrm{T})} = 10\log_{10}\left[\sum_{i=1}^{N} 10^{\frac{SEL_i}{10}}\right] - \mathrm{X}\ dB$$

In general, X = 10 log (T * 3600)

Common values of X:

T=24	X = 49.4
T= 8	X = 44.6

Notes :


NOISE DESCRIPTORS
SEL = 105 dB
Lmax = 101 dB
t> 91 dB = 6 sec
Leq = 97.0 dB
t > 65 dB = 17.5 sec
Leq = 92.8 dB
Legend
Instantaneous level
Leq for L>65 dB
Leq for L>91 dB
Sound Exposure Level (SEL)
A-weighted level (dB)
Time (seconds)
110
105
100
95
90
85
80
75
70
65
60
55
0
2
4
6
8
10
12
14
16
18
20

Notes :

NOISE DESCRIPTORS

Problem:

A house is situated in the approach path of a busy airport. Sixty 737s overfly the house on a given day at a nominal SEL of 93. Thirty-five L-1011s overfly the house producing an SEL of 95 dB each. The house is also overflown by Fifty-five Fokker F-100s at SELs of 88 dB each. What is the 24 hr LEQ at the house on that day?

Notes :

NOISE DESCRIPTORS

Answer:

$= 10 \log [(60 \times 10^{9.3}) + (35 \times 10^{9.5}) + (55 \times 10^{8.8})] - 49.4$

$=$ 11.4.234 $- 49.4$

$=$ <u>64.834 dB</u>

Notes :

NOISE DESCRIPTORS

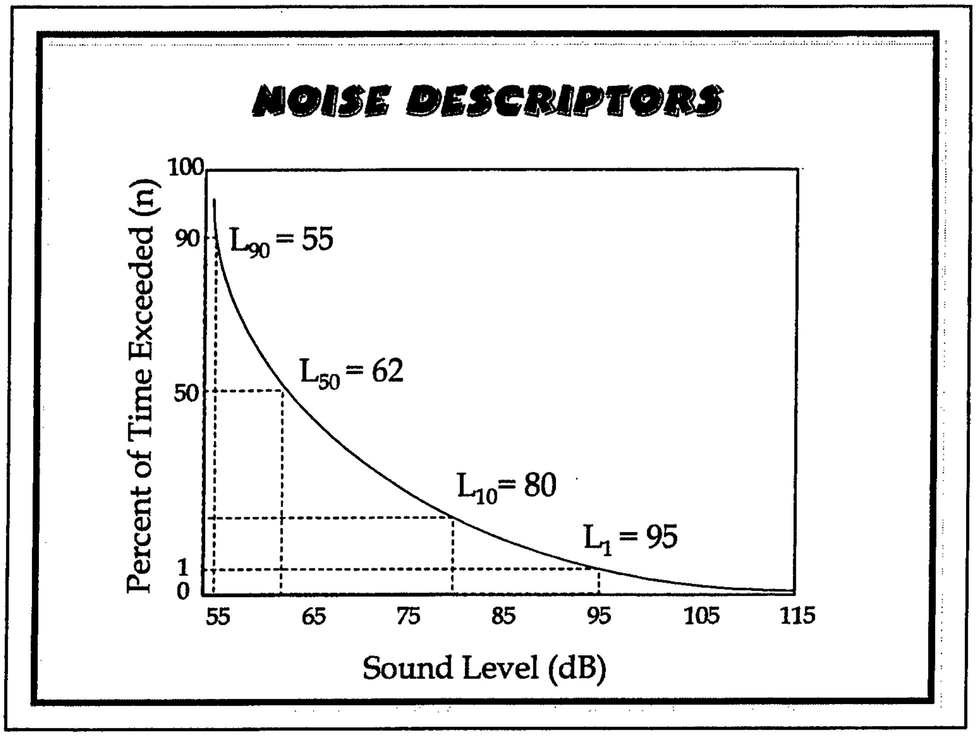
Exceedance Percentile Sound Level - L_n

The sound level that is exceeded n % of the time over the sound measurement period.

Common values of n:

90	Background/Ambient
50	Median Sound Level
10	Common Traffic Noise Metric
1	Infrequent Loud Events

Notes :

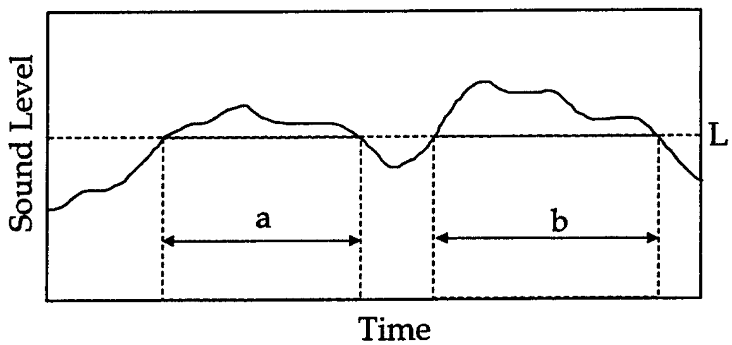

NOISE DESCRIPTORS
Percent of Time Exceeded (n)
100
90
50
1
0
$L_{90} = 55$
$L_{50} = 62$
$L_{10} = 80$
$L_1 = 95$
55
65
75
85
95
105
115
Sound Level (dB)

Notes :

NOISE DESCRIPTORS

Time Above Threshold

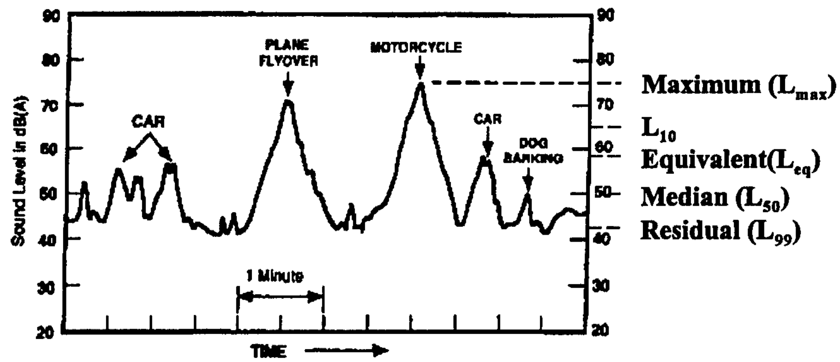
Amount of time during the measurement period that a given Sound Level (L) was exceeded



Time Above (TA) = a + b

Notes :

NOISE DESCRIPTORS



Maximum (L_{max})	**The maximum value of the sound over the period**
Exceedance (L_n)	**Sound Level exceeded n % of the time**
$L_{eq(T)}$	**Equivalent Sound Level over a T hr period.**

Notes :

APPLICATIONS OF NOISE ANALYSIS

- Occupational/Industrial Noise Exposure
- Residential/Community Noise Exposure

Notes :

OCCUPATIONAL NOISE EXPOSURE

Sources of hearing loss:

Occupational Noise

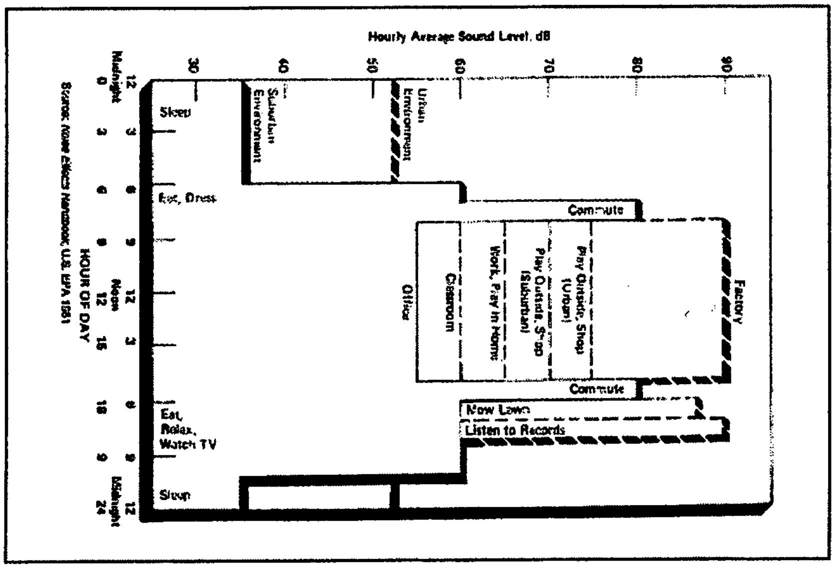
Non-occupational noise (sociocusis)

Aging of auditory system (presbycusis)

Non-acoustic factors (nosacousis) - e.g. drugs

Notes :

NOISE EXPOSURE



Notes :

OCCUPATIONAL NOISE EXPOSURE

Noise Sources:
Industrial/Manufacturing, Heavy Machinery, Aircraft, Sound Systems (Musicians), etc.

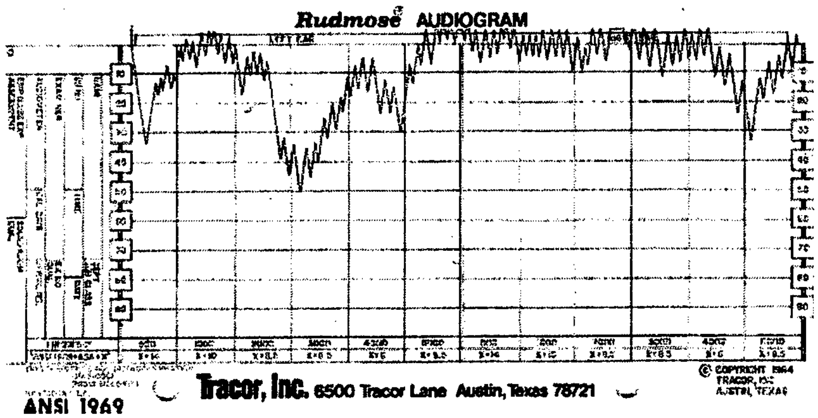
Prolonged Exposure leads to *Threshold Shifts*

temporary threshold shifts (TTS): temporary loss of hearing measured at a fixed interval after exposure to the noise.
Typical interval is 2 minutes (TTS_2)

Audiometric Testing: pre-exposure
post-exposure

Notes :

OCCUPATIONAL NOISE EXPOSURE



Sample Audiogram from an Audiometer

Notes :

OCCUPATIONAL NOISE EXPOSURE

Noise Induced Permanent Threshold Shifts (NIPTS):

with repeated exposure to noise of sufficient intensity (i.e. loud enough to show a TTS), NIPTS will occur.

No TTS, No NIPTS

Starts around 4000 Hz and spreads to other adjacent frequencies

Discovered through periodic audiometric screening

Notes :

OCCUPATIONAL NOISE EXPOSURE

Guidelines (set by Occupational Safety and Health Administration (OSHA)):
Noise dose = sum of partial doses (% of permissible dose)

$$\text{Partial dose} = \frac{\text{exposure time to given level}}{\text{maximum permissible time at given level}} * 100$$

Sound Level / dB(A)		max. permissible time (hrs)
<80		N/A
80		32
85		16
90		8
100		2
110		0.5
115		0.25
120	***levels above 115 dB(A)***	0.125
125	*** are not permissible ***	0.063
130		0.031

Notes :

OCCUPATIONAL NOISE EXPOSURE

Computing an *8-hour time weighted average (TWA)* from noise dose

$$\text{TWA (dB(A))} = 16.61 \log \frac{D}{100} + 90$$

Dose		TWA
10		73
25		80
50		85
75		88
100	**********permissible dose***********	90
115		91
130		92
150		93
175		94
200		95
400		100

Notes :

OCCUPATIONAL NOISE EXPOSURE

Dosimeter: a personal noise exposure measurement device that measures percent of noise dose received over a given period.

Criterion level: The continuous equivalent A-weighted sound level that constitutes 100% of an allowable exposure

Threshold: A-weighted level above which noise exposure is added to the total dose

Exchange Rate: The increase or decrease in decibels that is considered to be a doubling or halving of the noise dose (current OSHA compliance requires a 5 dB exchange rate)

Notes :

OCCUPATIONAL NOISE EXPOSURE

Problem:

A factory repair technician works on a faulty generator for 2 hrs. at a continuous exposure level of 95 dB(A). She later works on repairing a hydraulic lift for 3 hours at a level of 82 dB(A). That day the technician also gets called to diagnose problems with equipment in the machine shop for 1.5 hours and is exposed to 85 dB(A). The remainder of her workday is spent in his office doing paperwork where the noise level is 65 dB(A).

What is her total noise dose for this day?
What is the TWA for this noise dose?

Notes :

OCCUPATIONAL NOISE EXPOSURE

Answer:

2 hrs @ 95 dB	max @ 95 dB = 5 hrs
3 hrs @ 82 dB	max @ 82 dB = 25 hrs
1.5 hrs @ 85 dB	max @ 85 dB = 16 hrs

$$2/5 + 3/25 + 1.5/16 =$$

$$0.40 + 0.12 + 0.09 = 0.61 \times 100 = \underline{61\ \%}$$

$$\text{TWA} = [16.61 \times \log 0.61] + 90$$

$$= -3.57 + 90 = \underline{86.43\ \text{dB}}$$

Notes :

OCCUPATIONAL NOISE EXPOSURE

Impulsive noises: rise time less than 35 msec to peak intensity
duration less than 500 msec from peak to 20 dB down

Max. number per 8 hr workday = $10^{160-P/10}$

where P = peak SPL

Peak SPL	Max. number of events
150	10
140	100
130	1000
120	10000
115	31623
112	63096 - continuous

Notes :

OCCUPATIONAL NOISE EXPOSURE

Standards Committees and Organizations:

Occupational Safety and Health Administration (OSHA)
Occupational Noise Exposure

ANSI - ASA (Acoustical Society of America)

International Organization for Standardization (ISO)
Assessment of Occupational Noise Exposure for Hearing Conservation Purposes

Determination of Occupational Noise Exposure and Estimation of Noise-Induced Hearing Loss

Notes :

HEARING CONSERVATION PROGRAMS

Purpose:

- Establish legal records of noise exposure
- Minimize impact of noise exposure and reduce risk

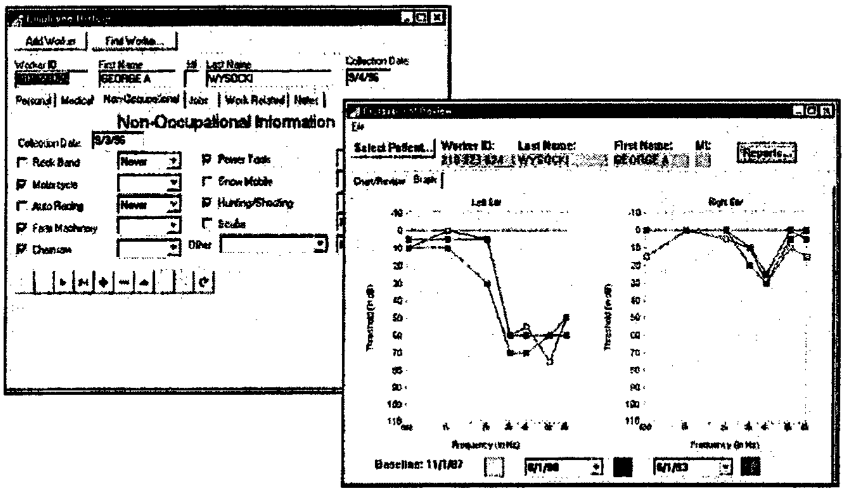
Components:

- Noise Education/Training
- Hearing Protection
- Audiometric Screening
- Noise Measurements/Modeling
- Noise Mitigation

Notes :

HEARSAF 2000

Cooperative research program between industry and NIOSH to develop a tool for hearing conservation programs (Currently under development)



Notes :

NOISE EDUCATION/TRAINING

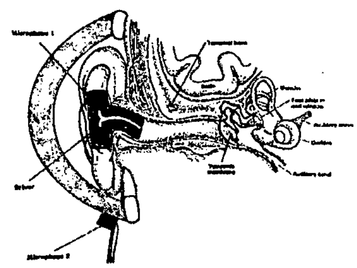
- Inform workers about dangers of noise exposure
- Encourage/ mandate use of hearing protection (adhere to appropriate Federal and State Laws)
- Train workers on proper use of hearing protection

Notes :

HEARING PROTECTION

Passive devices:
- Ear muffs
- Insert plugs
- Helmets
- Communication Units

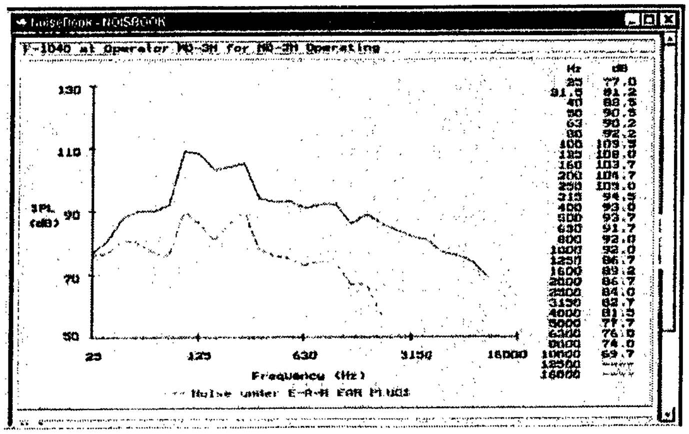
Active devices:
- Active Noise Reduction (ANR)
  - Headsets
  - Earplugs



Notes :

HEARING PROTECTION

Plot of noise levels with and without hearing protection - frequency dependent attenuation of hearing protector.



Notes :

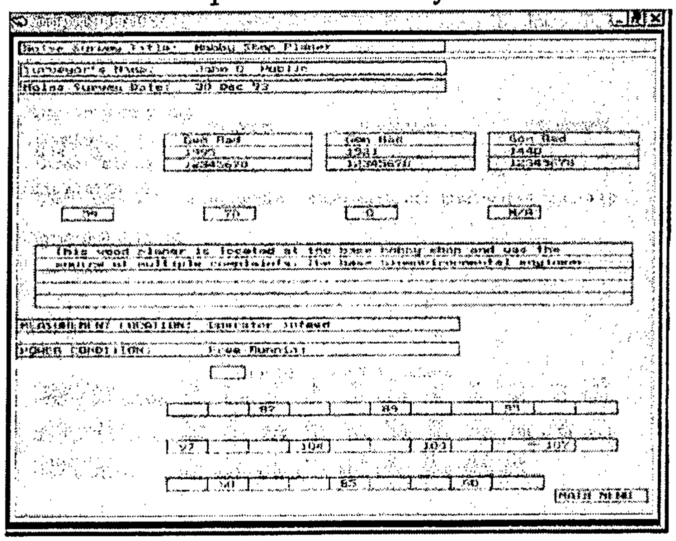
AUDIOMETRIC SCREENING

Initial Screening:	Determine pre-exposure hearing levels
Periodic Screening:	Periodic, routine hearing exams and audiometric screening to identify any permanent hearing loss
Traumatic Events:	Special hearing exams and audiometric testing after trauma to the ear caused by a noise event or non-acoustic trauma.
Termination:	Screening upon termination, retirement, etc.

Notes :

NOISE MEASUREMENTS

Sample Noise Survey Form



Notes :

NOISE MITIGATION

Noise can be *mitigated* at three locations:

- **THE SOUND SOURCE**
  - Acoustic Baffling
  - Enclosing Structures
- **THE TRANSMISSION PATH**
  - Increase distance between source and receiver
  - Sound Barriers
- **THE RECEIVER**
  - Hearing Protection Devices
  - Limiting Exposure Time

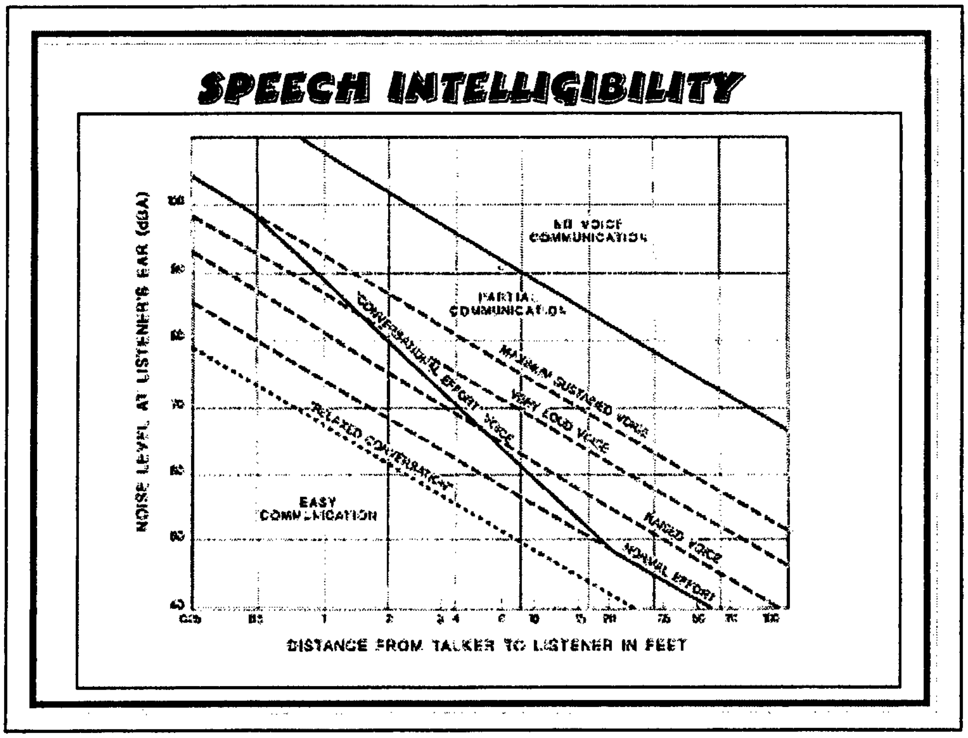
Notes :

SPEECH INTELLIGIBILITY

Speech Intelligibility is a function of:

- *Signal to Noise Ratio (SNR)* : Ratio of the continuous speech level to the background level over frequency bands of interest.
- Distance from the noise source(s)
- Distance from the speaker
- Speech Level/ Vocal Effort
- Augmentation/Amplification of Speech
- Attenuation of the noise (e.g., Active Noise Reduction - ANR)

Notes :


SPEECH INTELLIGIBILITY
NO VOICE COMMUNICATION
PARTIAL COMMUNICATION
MAXIMUM SUSTAINED VOICE
VERY LOUD VOICE
CONVERSATIONAL EFFORT VOICE
RELAXED CONVERSATION
RAISED VOICE
NORMAL EFFORT
EASY COMMUNICATION
NOISE LEVEL AT LISTENER'S EAR (dBA)
DISTANCE FROM TALKER TO LISTENER IN FEET

Notes :

SPEECH INTELLIGIBILITY

Speech Interference Level (SIL)

The arithmetic average of Sound Levels in decibels of the noise in the four octave bands centered at 500, 1000, 2000 and 4000 Hz - SIL(0.5, 1, 2, 4)

1/4 * (L @ 0.5 kHz + L @ 1kHz + L @ 2kHz + L @ 4kHz)

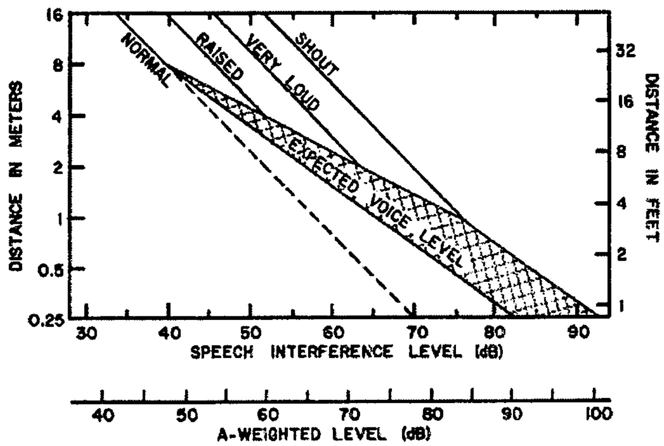
- ANSI Standard S3-14 (1977)
- Octave bands critical for speech

- Other common octave bands used
    - PSIL (Preferred-Octave SIL) - 0.5,1,2

Notes :

SPEECH INTELLIGIBILITY

Vocal effort as a function of distance between the SIL and distance between the speaker and listener.



Notes :

SPEECH INTELLIGIBILITY

Speech Interference Level (SIL)

Problem:

Using an octave band analyzer, you record the following sound levels in a cockpit during cruise flight:

68 dB @ 500 Hz
75 dB @ 1000 Hz
72 dB @ 2000 Hz
70 dB @ 4000 Hz

What is the SIL ? Using the Table, how loud would the pilot and copilot have to speak to communicate without intercoms if they are seated 1 meter apart ?

Notes :

SPEECH INTELLIGIBILITY

Speech Interference Level (SIL)

Answer:

Arithmetic Mean <u>NOT</u> Energy Avg.

[68 + 75 + 72 + 70] / 4

= <u>71.25 dB SIL</u>

Use Graph

1 meter x 71.25 >> <u>Very Loud</u>

Notes :

SPEECH INTELLIGIBILITY

Articulation Index (AI)

Weighted sum of the difference between measured noise levels and idealized (average) speech levels over a series of third octave bands from 200 to 5000 Hz.

Steps:

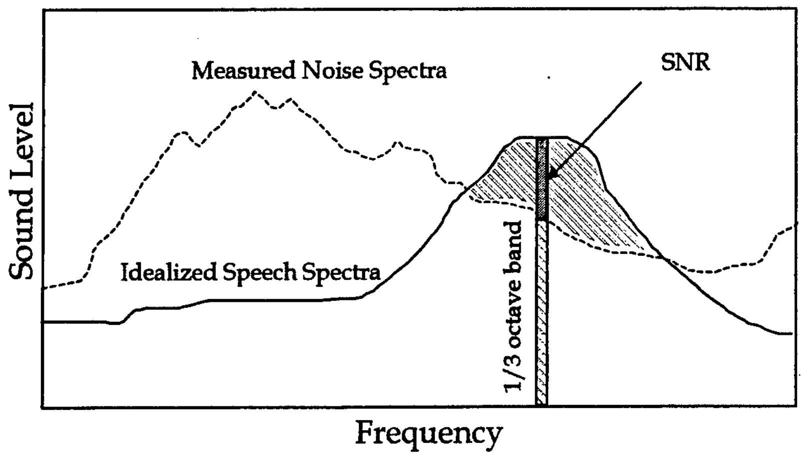
- Calculate Signal to Noise Ratio (SNR) for each 1/3 octave band
- Multiply by weighting factor for 1/3 octave band
- Add the weighted SNRs to derive AI

- use ANSI S3.5 (1969)

Notes :

SPEECH INTELLIGIBILITY

Articulation Index (AI)



Notes :

SPEECH INTELLIGIBILITY

Articulation Index (AI)

Band	Speech Peak	RMS Noise	S/N Ratio	Weight	Weighted S/N
200	78	74	4	0.0004	0.002
250	79	69	10	0.0010	0.010
315	80	67	13	0.0010	0.013
400	79	55	24	0.0014	0.034
500	78	52	26	0.0014	0.036
630	77	51	26	0.020	0.052
800	76	52	24	0.0020	0.048
1000	74	53	21	0.0024	0.050
1250	72	54	18	0.0030	0.054
1600	70	52	18	0.0037	0.067
2000	68	53	15	0.0037	0.056
2500	66	51	15	0.0034	0.051
3150	64	58	6	0.0034	0.020
4000	62	54	8	0.0024	0.019
5000	60	48	12	0.0020	0.024
				AI =	0.536

Notes :

SPEECH INTELLIGIBILITY

Articulation Index (AI)

Relationship of AI to Usability of a Communication System:

< 0.3	Unacceptable
0.3 - 0.5	Acceptable
0.5 - 0.7	Good
> 0.7	Very Good

Notes :

SPEECH INTELLIGIBILITY

Empirical Measures of Speech Transmission:

- Nonsense syllables
- Modified Rhyme Test (MRT)
- Phonetically Balanced Words (PB Words)

Other Considerations:

- Reverberant rooms (RT > 1.5 - 2 seconds)
- Non-continuous sound sources

Notes :

NOISE AND PERFORMANCE

Type of Noise

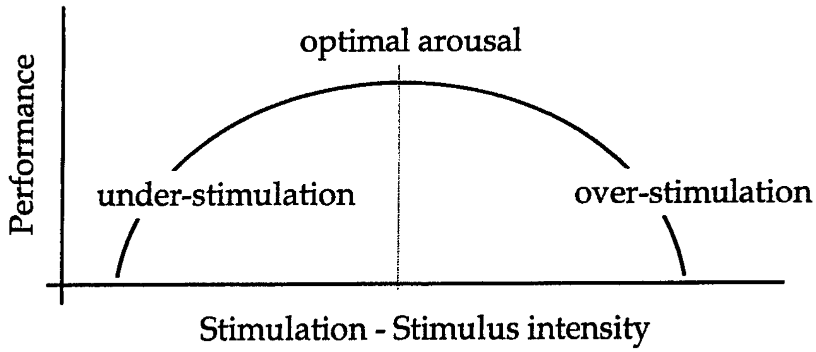
Controllability & Sense of Control

Tasks

- Motor Skills
- Vigilance
- Visual Search
- Semantic Processing
- Intellectual Tasks

Notes :

NOISE AND PERFORMANCE



Inverted-U relationship between arousal produced by stimulation and performance.

Notes :

NOISE AND PERFORMANCE

Results depend on:

- Familiarity with task
- Task cognitive and speech requirements
- Task difficulty
- Characteristics of the noise
- Familiarity with the noise (habituation)
- Perceived control of the noise
- Noise conditions during training

- Motor skills:
  - Balance

    High level, low frequency noise impairs
  - Reaction Time

    Increased error rates, particularly with high frequency noise

Notes :

NOISE AND PERFORMANCE

- Motor skills (continued):
  - Tracking

    DVs: Time on target, Root Mean Square (RMS) Error

    Minimal effect of noise, effects largest during initial practice

    levels >120 can impair tracking

- Vigilance Tasks:

  varying results

  Noise can increase false alarm rate

  Noise can decrease vigilance decrement in correct detections.

Notes :

NOISE AND PERFORMANCE

- Visual Search Tasks:
  - complex, highly studied topic
  - results vary
    - performance best at noise level presented during training (see Teichner, 1963)

- Semantic Processing:
  - Stroop task: Noise > 85dB increases interference
  - Classification Task: Noise increases errors and sort time among children, increases sort time among adults
  - Proofreading/verification: surface structure detections not impaired, higher level (semantic) processing impaired

Notes :

NOISE AND PERFORMANCE

- Intellectual Tasks:
  - Clerical Ability Test:
    Noise slows performance
    but reduces errors
  - Weschler Skills Test:
    Noise reduced performance
    but not among highly practiced subjects
  - Mental Arithmetic:
    Noise increased calculating time
  - Sternberg Task:
    Noise effects rate of central processing

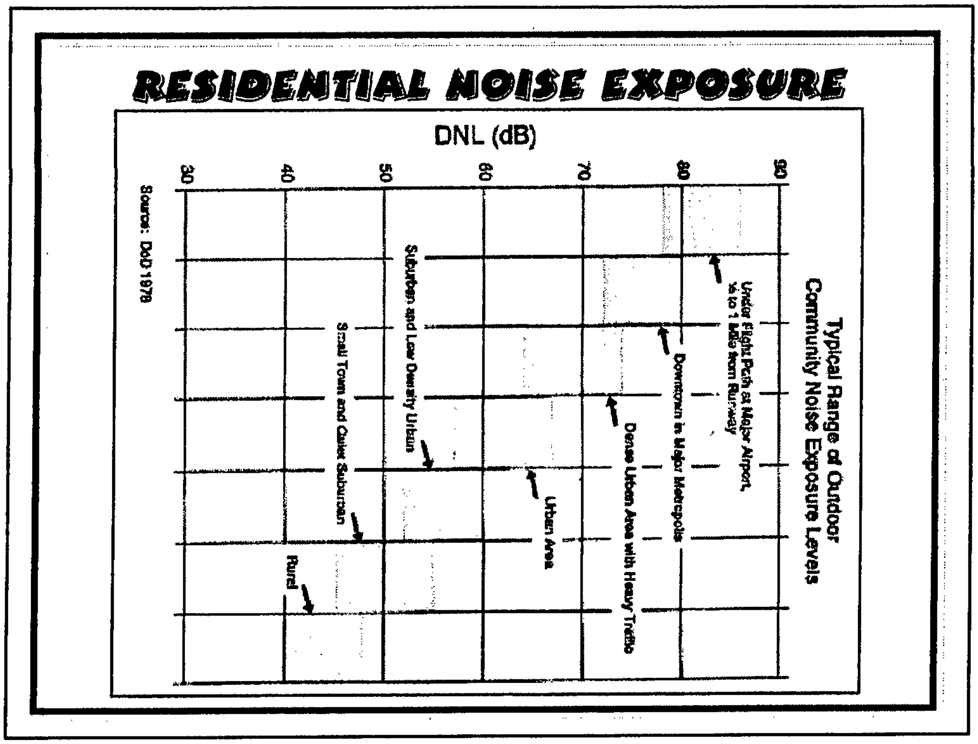
Notes :

RESIDENTIAL NOISE EXPOSURE

Major Sources :

- Industry
  - Plants
- Utilities
  - Powerplants
  - Transformers
- Transportation
  - Highway
  - Rail
  - Aircraft

Notes :


RESIDENTIAL NOISE EXPOSURE
DNL (dB)
30
40
50
60
70
80
90
Typical Range of Outdoor
Community Noise Exposure Levels
Under Flight Path at Major Airport,
½ to 1 Mile from Runway
Downtown in Major Metropolis
Dense Urban Area with Heavy Traffic
Urban Area
Suburban and Low Density Urban
Small Town and Quiet Suburban
Rural
Source: DoD 1978

Notes :

RESIDENTIAL NOISE EXPOSURE

Description	Typical Range DNL in dB	Ave DNL in dB	Population Density People/Sq.Mi
Quiet Suburban Residential	48-52	50	630
Normal Suburban Residential	53-57	55	2,000
Urban Residential	58-62	60	6,300
Noisy Urban Residential	63-67	65	20,000
Very Noisy Urban Residential	68-72	70	63,000

Source: U.S. EPA 1974

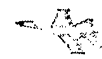
Notes :

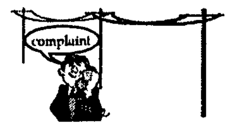
COMMUNITY REACTION

Effects of Noise on People (Residential Land Uses Only)

Day-Night Average Sound Level in Decibels:	Effects: Hearing Loss Qualitative Description	Annoyance % of Population Highly Annoyed	Average Community Reaction	General Community Attitude Towards Area
75 and above	May Begin to Occur	37%	Very Severe	Noise is likely to be the most important of all adverse aspects of the community environment.
70	Not Likely	22%	Severe	Noise is one of the most important adverse aspects of the community environment.
65	Will Not Occur	12%	Significant	Noise is one of the important adverse aspects of the community environment.
60	Will Not Occur	7%	Moderate	Noise may be considered an adverse aspect of the community environment.
55 and below	Will Not Occur	3%	to Slight	Noise considered no more important than various other environmental factors.

SOURCE: FICON 1992





Notes :

ENVIRONMENTAL NOISE AND ANNOYANCE

Factors influencing annoyance:

- Time of Day
- Impulsive sounds
- Onset Rate
- Strong Low Frequency Content
- Significant Tonal Components
- Ambient/Background Noise Levels ?

Notes :

ENVIRONMENTAL NOISE AND ANNOYANCE

Time of Day:

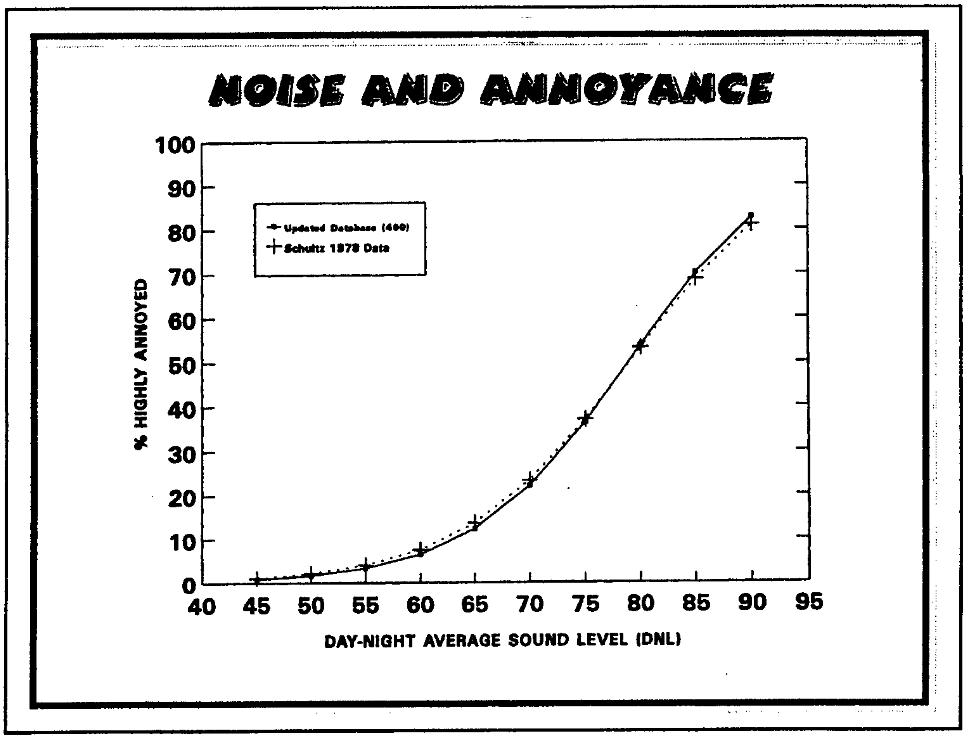
Day-Night Average Sound Level (DNL):

- A single number measure of community noise exposure.
- A modified 24 hr LEQ with a 10 dB penalty applied to nighttime sound levels from 10 pm until 7 am

Community Noise Equivalent Level (CNEL):

- Includes a 5 dB penalty to evening sound levels occurring between 7pm and 10 pm
- Used in California

Notes :


NOISE AND ANNOYANCE
Updated Database (400)
Schultz 1978 Data
% HIGHLY ANNOYED
100
90
80
70
60
50
40
30
20
10
0
40
45
50
55
60
65
70
75
80
85
90
95
DAY-NIGHT AVERAGE SOUND LEVEL (DNL)

Notes :

ENVIRONMENTAL NOISE AND ANNOYANCE

Adjustment Factors (based on pending ANSI Standard S12.9-199x - Part 4) :

	dB adjustment
• General Broadband Sound	0
• Onset Rate (R):	
$R < 15$ dB/s	0
$15 <= R < 150$ dB/s	11 log (R/15)
$R >= 150$ dB/s	11
• Impulsive	
Regular Impulsive	5
Highly Impulsive	12
• Tonal Component	5

Notes :

ENVIRONMENTAL NOISE AND ANNOYANCE

Adjustment Factors (continued):

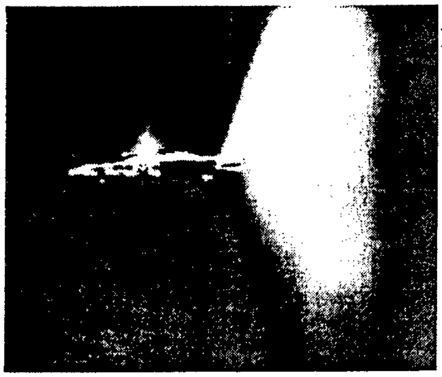
- High Energy Impulsive (large blasts and sonic booms) — Use C-weighted Convert to A-wt: $L_{(a)} = 2(L_c) - 103$
- Strong Low Frequency Content: $L_{(a)} = 2(L_{LF}) - 75 + 10 \log (T/1)$

where:
L_{LF} = sound level for 16 Hz, 31.5, and 63 Hz octave bands
T = duration of interest when low frequency is present (sec)

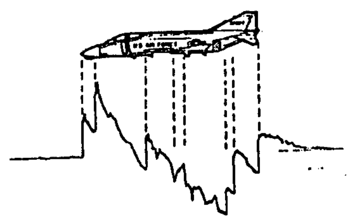
- adjusts for effects caused by rattle

Notes :

SONIC BOOMS



F-4C SONIC BOOM SIGNATURE



Aircraft moving slightly below Mach 1 and faster can produce sonic booms (Mach 1 = speed of sound)
Sound waves are compressed to form a pressure wave (N-wave)
Propagation: Carpet Boom - *Mach Cones* reaching the ground
Focused Boom - Accelerating maneuver focuses the energy of the boom

Notes :

ENVIRONMENTAL NOISE AND ANNOYANCE

Low Ambient/Background Sound Levels :

- Rural Areas
- Parks and Wilderness (Outdoor Recreationalists)
  - Audibility
  - Expectations (e.g., "natural quiet")

(currently no specific recommendations available)

Other Potential Noise Sensitive Locations:

- Schools
- Places of Worship
- Public Meeting Sites

Notes :

ENVIRONMENTAL NOISE AND SLEEP DISTURBANCE

- **Sleep is a basic human need**
  - Sleep deprivation studies
  - light sleep/quiet sleep
    - body fatigue
  - deep sleep/ active sleep
    - mental fatigue
    - rapid eye movements (REM)
    - average 1.5 hours/night

Notes :

ENVIRONMENTAL NOISE AND SLEEP DISTURBANCE

How to Measure Sleep ?

- Sleep States
  - Electroencephalograms (EEGs)
- Awakenings
  - Actimetery: Movement Sensors
  - Behavioral Responses: Response Panel
- Sleep Quality
  - Duration
  - Perceived Quality of Rest

Notes :

ENVIRONMENTAL NOISE AND SLEEP DISTURBANCE

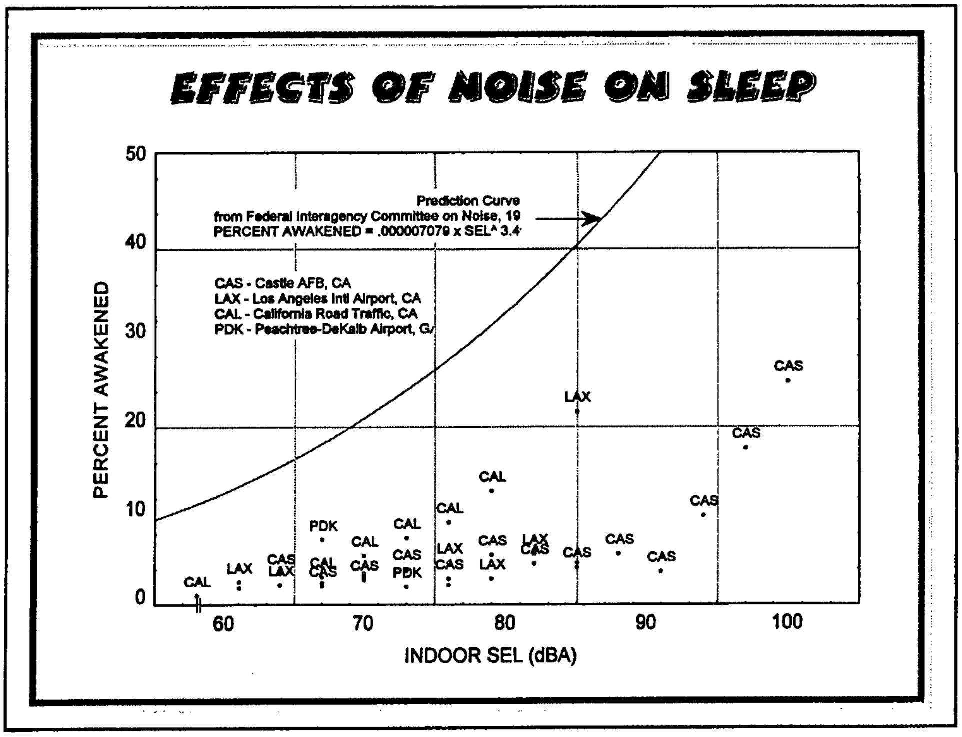
- Sleep States (EEG):

• Awake	Alpha and Beta activity	- low amp., high freq.
• Stage 1	Theta activity	
• Stage 2	Spindles, K-complexes	- slow waves
• Stage 3	Delta activity	(low freq., increasing
• Stage 4	strong Delta activity	amp.)
• REM	Theta and Beta activity	- *paradoxical sleep* aroused EEG pattern low amp., high freq.

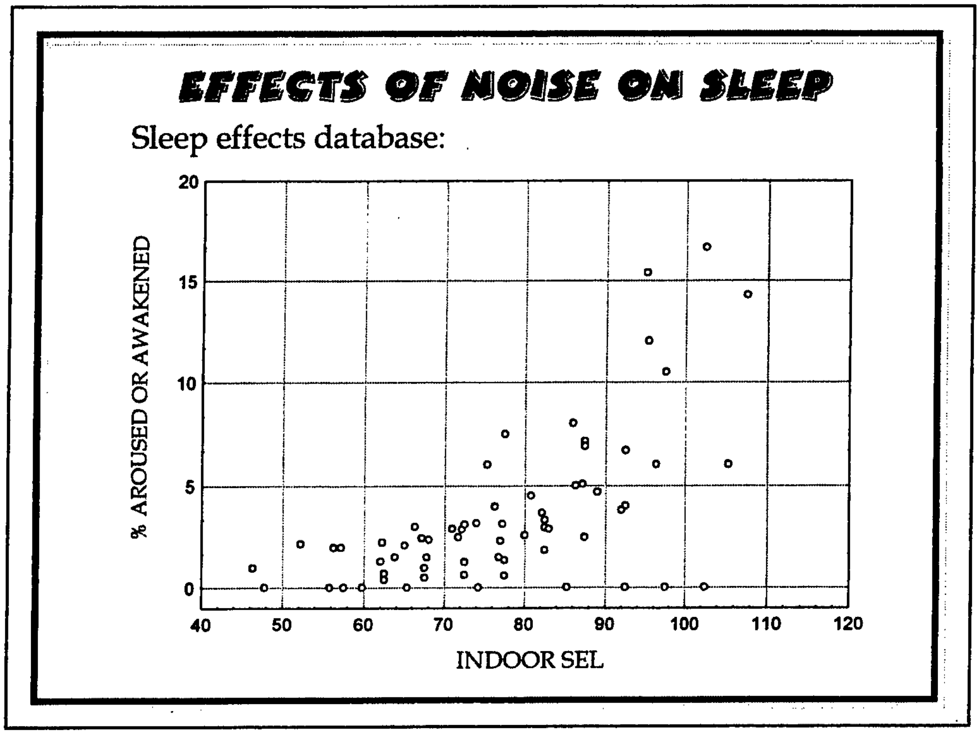
- Noise Levels above the ambient required to produce a change in sleep states:

• Stage 2 (Light) to Stage 1 (Shallow)	30 dB(A)
• Stage 3 (Deep) to Stage 2 (Light)	50 dB(A)
• Stage 4 (Very Deep) to Stage 3 (Deep)	80 dB (A)

Notes :


EFFECTS OF NOISE ON SLEEP
Prediction Curve
from Federal Interagency Committee on Noise, 19
PERCENT AWAKENED = .000007079 x SEL^ 3.4
CAS - Castle AFB, CA
LAX - Los Angeles Intl Airport, CA
CAL - California Road Traffic, CA
PDK - Peachtree-DeKalb Airport, G
PERCENT AWAKENED
INDOOR SEL (dBA)
0
10
20
30
40
50
60
70
80
90
100

Notes :


EFFECTS OF NOISE ON SLEEP
Sleep effects database:
% AROUSED OR AWAKENED
0
5
10
15
20
40
50
60
70
80
90
100
110
120
INDOOR SEL

Notes :

ENVIRONMENTAL NOISE AND HEALTH

Claims of adverse health effects from environmental noise include:

- Hearing Damage
- Cardiovascular Disorders
- Effects on the Unborn
- Mental and Social Well Being
- Physiological Stress Effects
- Interference with Learning
- Controversial Topics

Notes :

NOISE MODELING

Increased computer power has made noise modeling more accurate:

Components:

- Noise Source: Point source (monopole) - simplest
  Line source
  Area source
- Attenuation: Inverse square law +/- 6 dB
  spherical spreading
- Propagation: Air absorption
  - frequency dependent
  - weather (temperature, humidity ...)
  - Ground attenuation
    - reflected signal
    - impedance
    - hard vs. soft surface
    - terrain
  - Surfaces
    - walls, ceilings, barriers ...

Notes :

NOISE MODELING

- Near field vs. far field:
  Extrapolation not possible in near-field (<200 ft)
- Types of Noise Models:
  Architectural Noise Models
  Highway Noise Models
    Barriers
  Railroad Noise Models
  Aircraft Noise Models (e.g. INM, NoiseMap)
- Advantages of Modeling:
  Impossible or impractical to measure at all locations of interest or potential impact.
  Scientific estimate of noise exposure

  Accuracy is highly dependent on the quality of data input into the model

Notes :

NOISE MODELING

Points of Contact

FAA Integrated Noise Model (INM)
Dr. Jake Plante
FAA Office of Environment & Energy
AEE-120
800 Independence Ave SW
Washington, DC 20591
(202) 267-3539

US Air Force Noise Models
(Aircraft Noise and Sonic Boom)
Mr. Robert Lee
AL/OEBN
2610 Seventh Street
Wright-Patterson AFB, OH 45433-7901
(937) 255-3605

US Army Noise Models (Blast)
Dr. Larry Pater
US Army
Construction Engineering Research Laboratory
PO Box 9005
Champaign, IL 61826-9005
(217) 352-6511 x375 or (800) USA-CERL

DOT Highway Transportation Noise Models
Dr Greg Fleming
DOT Volpe Center
Kendall Square
Mail Code DTS75
Cambridge, MA 02142-1093
(617) 494-2372

Notes :

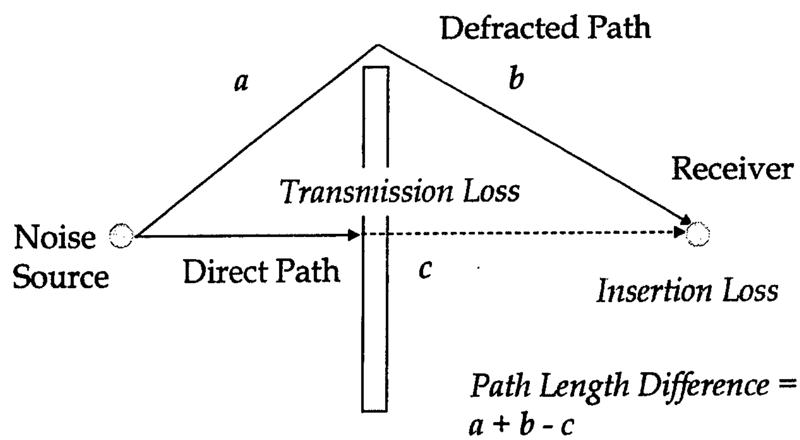
NOISE MITIGATION

- Passive Noise Reduction
  - Source - Baffling, Enclosures, Scheduling
  - Transmission Path - Sound Barriers, Land Use Planning
  - Receiver - Sound Insulation, Masking, Hearing Protection
- Active Noise Reduction
  - Large Scale ANR Devices
  - ANR Hearing Protection

Notes :

NOISE MITIGATION

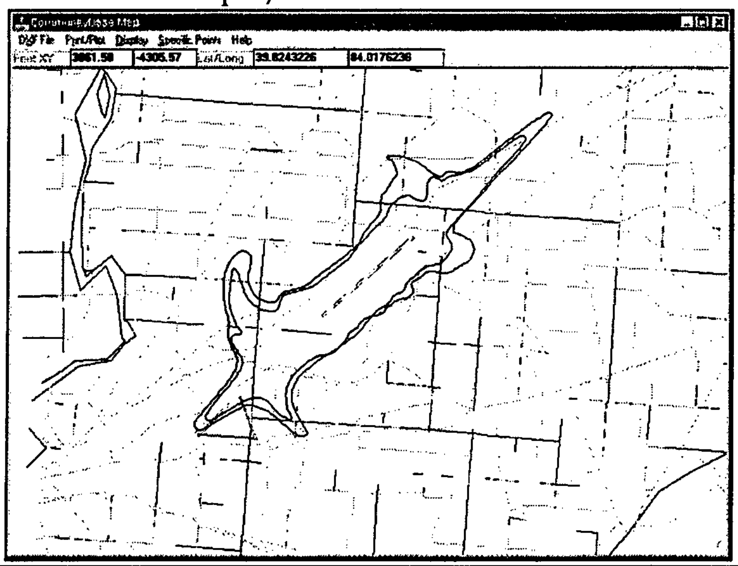
Barriers



Notes :

LAND USE PLANNING

Airport/airbase noise contours:



Notes :

LAND USE PLANNING

Recommended Indoor Noise Levels

Location/Activity	All Sources (LEQ - dB(A))	Continuous Interior Sources (Level - dB)
Community:		
Sleeping	45	40
Residential	50	40
Classrooms, Libraries Churches, Hospitals	50	40
Office:		
Private Office, Conference Room	45	40
Workspaces w/ Telephone Use	55	45
Workspaces w/ Occasional Speech Communication and Telephone Use	60	55
Workspaces w/ Infrequent Speech Communication and Telephone Use	70	60

Notes :

NOISE MITIGATION

Noise Level Reduction Values for Typical Building Materials

Construction	NLR in dB
• Conventional Wood Frame (Windows Open)	15-20
• Conventional Wood Frame (Windows Closed)	25-30
• Conventional Wood Frame (No Windows or 1/4" Sealed Glass Windows)	30-35
• 1/8" Sealed Glass Window	20-25
• 1/4" Sealed Glass Window	25-30
• Walls and Roof (20-40 lbs. / ft^2)	35-40
• Walls and Roof (40-80 lbs. / ft^2)	40-45
• Heavy Walls and Roof (>= 80 lbs. / ft^2)	45-50

Notes :

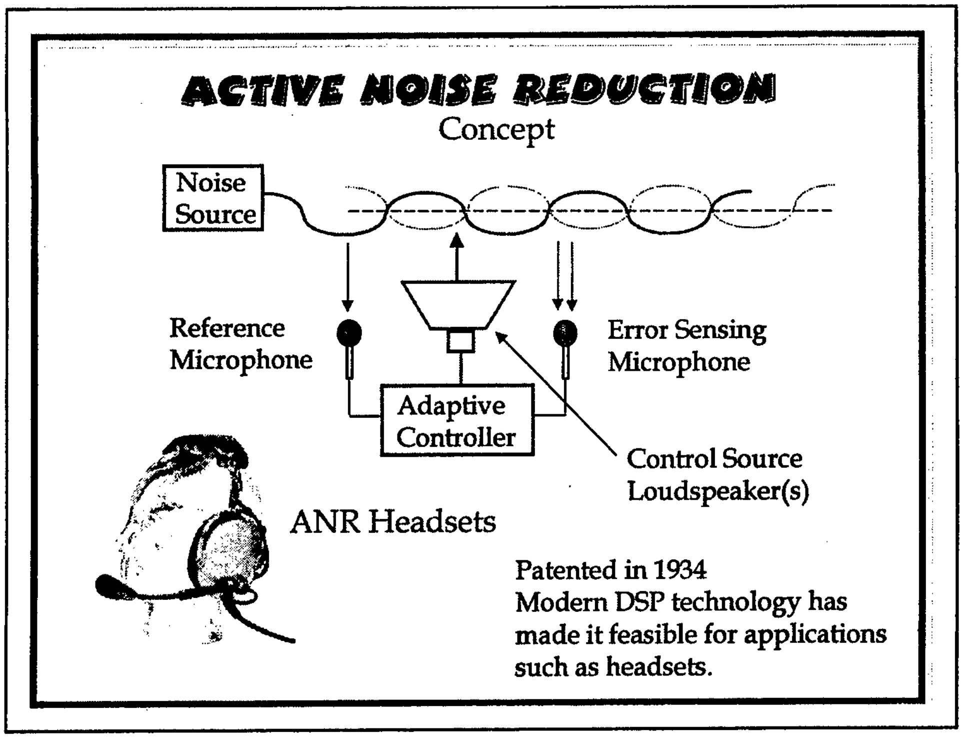
NOISE MITIGATION

Sound level reduction for typical residential structures:

	Windows Open	Windows Closed
Warm Climate	12 dB	24 dB
Cold Climate	17 dB	27 dB
Approximate national average	15 dB	25 dB

Source: U.S. EPA 1974

Notes :

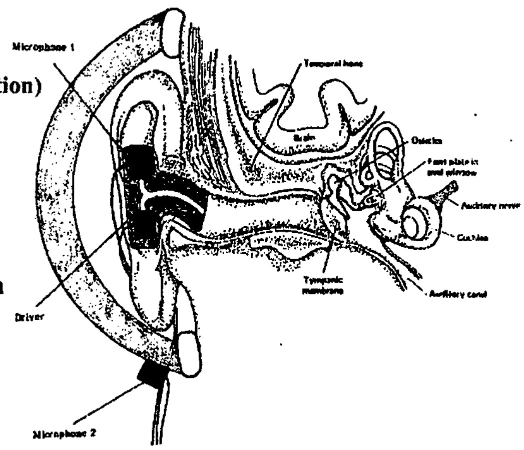

ACTIVE NOISE REDUCTION
Concept
Noise Source
Reference Microphone
Error Sensing Microphone
Adaptive Controller
Control Source Loudspeaker(s)
ANR Headsets
Patented in 1934
Modern DSP technology has made it feasible for applications such as headsets.

Notes :

ACTIVE NOISE REDUCTION

ANR EARPLUG

- Above the Ear (40 dB Attenuation)
  - 30 dB Passive attenuation
  - +10 dB Active attenuation
  - 20 to 400 Hz
- In the Ear (50 dB Attenuation)
  - 40 dB Passive Attenuation
  - +10 dB Active Attenuation
  - 20 to 3k Hz



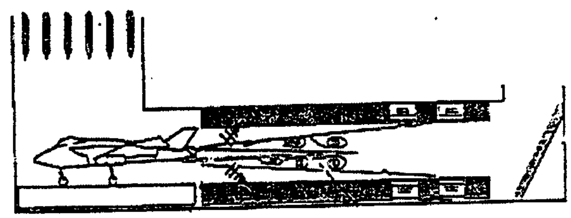
Notes :

ACTIVE NOISE REDUCTION

ACTIVE LINEAR FOR HUSH-HOUSE

Results

- Demonstrated concept on quarter scale model
- Attenuations of 8 to 15 dB in 32-320 Hz (8 - 80 Hz full scale)
- Concept ready for full scale demonstration



Notes :

ACTIVE NOISE REDUCTION

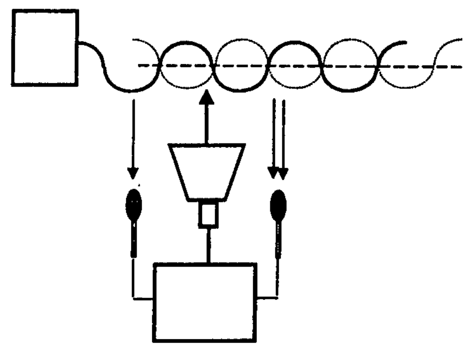
PORTABLE ANR SYSTEM

Results

- Demonstrated concept of local shadow zone

- 1/3 octave band attenuations up to 15 dB (20 to 315 Hz)

- Concept ready for technology demonstration



Notes :

ACTIVE NOISE REDUCTION

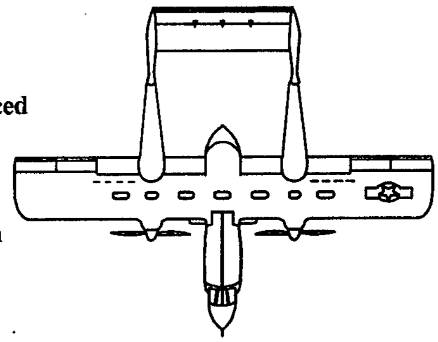
TURBO PROP
DIGITAL CONTROLLER

Concept Results

- **OV-10B Aircraft**
- **In-flight cockpit noise is reduced**
- **Far-Field**

  Changes directivity pattern

  Does not effect overall noise levels



Notes :

AUDITORY DISPLAYS

Why ?

Advantages and Disadvantages of Auditory Displays:

Advantages:

- Alerting - good attention-getter
- Orienting - if localized, can draw attention
- Not fixed in one spatial position

Disadvantages:

- Transitory - information must be remembered
- Not always detectable
- Limited number can be readily distinguished

Notes :

AUDITORY DISPLAYS

When ?

Environmental and Task Factors

- High visual workload
- Visual capabilities impaired by environment (e.g., lighting)
- Information is continuously changing
- Task involves a high degree of movement or isolation from visual displays
- Simple, short messages
- Message will not be referenced later
- Message deals with events in time
- Message calls for immediate action (alert, warning)

Notes :

RECOMMENDATIONS FOR AUDITORY

ALARM AND WARNING DEVICES

from Human Engineering Guide to Equipment Design

Conditions	Design recommendations
If distance to listener is great	Use high intensities and avoid high frequencies
If sound must bend around obstacles and pass through partitions	Use low frequencies
If background noise is present	Select alarm frequency in region where noise masking is minimal
To demand attention	Modulate signal to give intermittent "beeps"
To acknowledge warning	Provide signal with manual shutoff so that it sounds continuously until action is taken.

Notes :

AUDITORY DISPLAYS

How ?

- Criteria
  - Detection
  - Discriminability
- Alarms - Tones and Patterns
- Speech
  - Natural Speech
  - Synthetic Speech
  - Voice

Notes :

AUDITORY DISPLAYS

Detection:

- Signal can be *masked* by ambient and background noise.
- *masked threshold*
    - level needed to attain 75% correct detection of the signal when presented in one of two intervals using a two alternative forced choice response.
- Function of the background noise levels within specific *critical bands*

critical band : A inverted-U shaped filter corresponding to psychophysically determined masking patterns. Bandwidth is a function of frequency and is generally 10-20% of the frequency of interest, so higher frequencies have higher bandwidths.

Notes :

AUDITORY DISPLAYS

Detection:

Guidelines for detectability:

- Signal levels 6-10dB > *masked threshold* are sufficient for 100% detectability in *controlled test* situations
- Signal levels 15-16 dB > *masked threshold* should be sufficient for situations requiring a rapid response
- To minimize annoyance and disruption of communication, signal level should be < 30 dB above *masked threshold*
- If required signal level >= 115 dB, consider non-auditory display

Notes :

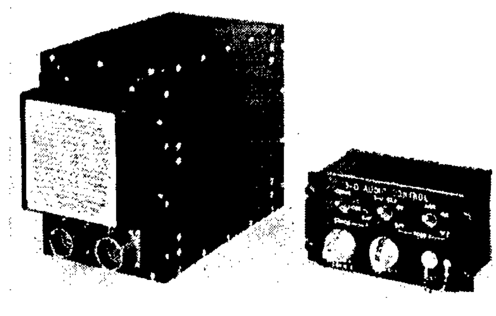
AUDITORY DISPLAYS

Discriminability:

- Information Rate:
  - 75 bits/sec - normal speech, high information rate
  - 25 bits/sec - maximum practical limit
  - 5 bits/sec - good rate for most applications
- Duration: >100 msec for detection, longer to discriminate pattern, will vary depending code complexity and information rate.
- Number of Unique Signals: 6 + or - 2, (2 attensors - priority)
- Temporal Patterns and Coding: use of *carrier frequencies* and repetitions; use onset times > 10 dB/msec to avoid startle.
- Localization: use localized sources, 3-D audio to isolate sources and reduce background noise interference
- Speech: use different speakers, use limited vocabulary, maximize redundancy, standardize phrasing

Notes :

3-D AUDITORY DISPLAYS



- Technology
- Applications

Notes :

3-D AUDITORY DISPLAYS

Technology

- Digital Signal Processing (DSP) filters create *Head Related Transfer Functions (HRTFs)* across auditory space (elevation, azimuth) and auditory frequencies in real time.

- Head trackers provide inputs regarding head position relative to the virtual auditory source

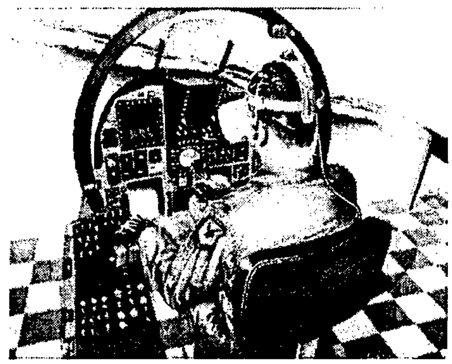
- Playback over stereo headphones produces a sensation of *localization* outside the head rather than *lateralization* within the head.

Notes :

3-D AUDITORY DISPLAYS

Applications

- Virtual Reality
- Tactical Displays
- Commercial Aircraft
  Auditory
  Traffic
  Collision
  Avoidance
  Systems
  (TCAS)
- Industry
- Consumer Products



Notes :

AUDITORY DISPLAYS

Where ?

Applications of Auditory Displays:

- Aviation and Aerospace
- Computers
- Communication Systems
- Manufacturing/ Industrial
- Utilities (Power Plants, etc.)

Notes :

Auditory Signals in an F-16:

SIGNAL	CONDITIONS	CHARACTERISTICS
Landing Gear	Low, Slow, Descending without landing gear down	250 Hz repetitive no volume control, but silencer
Low Airspeed	Angle of Attack > 15 degrees with landing gear down	250 Hz steady no volume control, but silencer
Low Speed/High Altitude	Airspeed too low for altitude landing gear up	250 Hz steady no control
Threats	Radar identifies enemy or pilot selects target	1600-5000 Hz one tone per target volume control
	New enemy detected	1000 Hz seven beeps volume
	Locked on by enemy radar Fired On	1000 Hz 5 beeps/sec volume, on/off control
Instrument Landing System (ILS)	Instrument approach	400 Hz outer marker 1300 Hz middle marker 3000 Hz inner marker Morse code volume, on/off control
Tactical Air Navigation System (TACAN)	Navigation signal reception	1350 Hz at 30 sec intervals Morse code volume, on/off control
Low Altitude/Terrain	Altitude lower than pilot selected setting	800 Hz on/off switch
General Warning	Red warning light lit System malfunction	Female voice: "Warning, warning, warning ...." off control
General Caution	Amber caution light lit	Female voice: "Caution, caution ...." off control

Notes :

AUDITORY DISPLAYS

Class Exercises

You are approached to consult on the human factors design of an auditory display for a Ground Proximity Warning System (GPWS) for the cockpit of a fighter aircraft. Discuss the advantages and disadvantages of using an auditory display for this application. Discuss the environmental and task factors you would consider, and determine how you would implement this auditory display.

Notes :

AUDITORY DISPLAYS

Class Exercises

A nuclear power plant currently has 20 auditory displays. They are all tones that vary in their pitch and temporal patterning. All were shown by psychophycical testing to be highly descriminable in laboratory settings. The control room where these displays are presented has a high ambient noise levels. Would you consider changing these displays? Why? What alternative displays would you consider? Why? What potential limitations are there with these alternatives ?

Notes :

AUDITORY DISPLAYS

Class Exercises

A large communications firm wants to develop an on-line internet customer service center. In order to make the technology user friendly, they want to incorporate voice and sound displays to assist users in navigating the web site. Discuss what displays you would consider. What types of displays do you think would be most "user friendly"? What types of information can be provided by auditory displays ?

Notes :

PRODUCT SOUND QUALITY

The application of scientific research in human auditory perception and psychoacoustics toward the analysis and design of consumer products.

Notes :

PRODUCT SOUND QUALITY

Elements:

Marketing, Engineering &
Psychology (Psychoacoustics)

Products:

Automobiles - road noise, exhaust, doors
Appliances
Heating, Ventilating, Air Conditioning (HVAC)
Stereos/entertainment systems ...

Qualitative aspects of the sound:

Quiet, Sharpness, Roughness ...

Methods:

Panels, focus groups, sound quality evaluators
Psychoacoustic scaling techniques ...

Payoffs: $$$

Notes :

WRAP UP

What were the most useful things you learned from this workshop?

How will you apply what you learned from this workshop?

Notes :

BIBLIOGRAPHY

Atkinson, R.C., Hernstein, R. J., Lindzey, G., & Luce, R. D. (Eds.) (1988). *Stevens' Handbook of Experimental Psychology* (2nd Ed.). New York, NY: Wiley.

Beranek, L. L. (1993). *Acoustics.* Woodbury, NY: Acoustical Society of America.

Boff, K. R. & Lincoln, J. E. (Eds.) (1988). *Engineering Data Compendium: Human Perception and Performance.* Wright-Patterson AFB, OH: Human Engineering Division, Harry G. Armstrong Aerospace Medical Research Laboratory.

Boff, K. R., Kaufman, L., & Thomas, J. P. (Eds.) (1986). *Handbook of Perception and Human Performance.* New York, NY: John Wiley and Sons.

Carlson, N. R. (1991). *Physiology of Behavior* (4th ed.). Needham Heights, MA: Allyn and Bacon.

Goldstein, E. B. (1984). *Sensation and Perception* (2nd ed.). Belmont, CA: Wadsworth Publishing.

Green, D. M. & Swets, J. A. (1988). *Signal Detection Theory & Psychophysics.* Los Altos, CA: Peninsula Publishing.

Handel, S. (1989). *Listening: An Introduction to the Perception of Auditory Events.* Cambridge, MA: MIT Press.

Henderson, D., Hamernik, R. P., Dosanjh, D. S., & Mills, J. H. (Eds.) (1976). *Effects of Noise on Hearing.* New York, NY: Raven Press.

Kantowitz, B. H. & Sorkin, R. D. (1983). *Human Factors: Understanding People-System Relationships.* New York, NY: John Wiley & Sons.

Moore, B. C. J. (1977). *Introduction to the Psychology of Hearing* (2nd. ed.) San Diego, CA: Academic Press.

Moore, B. C. J. (Ed.) (1995). *Hearing.* San Diego, CA: Academic Press

Morgan, C. T., Cook, J. S., Champanis, A., & Lund, M. W. (1963). *Human Engineering Guide to Equipment Design.* New York, NY: McGraw-Hill.

Parker, J. F. & West V. R. (Eds.) (1973). *Bioastronautics Data Book* (2nd ed.). NASA SP-3006.

Pickles, J. O. (1988). *An Introduction to the Physiology of Hearing* (2nd Ed.) San Diego, CA: Academic Press.

Salvendy, G. (Ed.) (1987). *Handbook of Human Factors.* New York, NY: John Wiley & Sons.

Sanders, M. S. & McCormick, E. J. (1993). *Human Factors in Engineering and Design* (7th ed.). New York, NY: McGraw-Hill.

Schultz, T. J. (1982). *Community Noise Rating* (2nd Ed.). New York, NY: Applied Science Publishers.

Stevens, S. S. & Davis, H. (1983). *Hearing: Its Psychology and Physiology.* New York, NY: American Institute of Physics.

Stevens, S. S. (Ed.) (1951). *Handbook of Experimental Psychology* (2nd ed.) New York, NY: John Wiley & Sons.

Van Cott, H. P. & Kinkade, R. G. (1972). *Human Engineering Guide to Equipment Design.* Washington, D.C.: U. S. Government Printing Office.

APPENDIX A

SUGGESTED COURSE SCHEDULE

SOUND BASICS: A PRIMER IN PSYCHOACOUSTICS

TOPIC	TIME
Introduction/Welcome	0830-0845
1. Fundamentals of Psychoacoustics	
a) The Sound Source i) Physical Properties of Sound a) Descriptors of Sound (1) Intensity (2) Frequency (3) Time	0845-1015
***** BREAK *****	1015-1030
ii) The Receiver a) Physiology (1) The Ear (2) Neural Pathways b) Psychoacoustics (1) Methods (2) Loudness (3) Pitch (4) Temporal Patterning (5) Spatial Hearing (6) Speech Perception	1030-1200
***** LUNCH *****	1200-1300
2. Applied Psychoacoustics	
a) Noise Analysis i) Weighting ii) Summation iii) Spectral Analysis iv) Bands	1300-1400
***** BREAK *****	1400-1415

b)	Applications of Noise Analysis i) Industrial/Occupational Noise Exposure a) Exposure Limits b) Hearing Loss c) Hearing Conservation Programs d) Speech Intelligibility/Speech Interference e) Task Interference ii) Residential Noise Exposure a) Annoyance b) Sleep Disturbance c) Stress and Health Effects iii) Noise Modeling iv) Noise Mitigation a) Passive Noise Reduction b) Active Noise Reduction c) Education and Hearing Conservation	1415-1530
	******* BREAK *******	1530-1545
c)	Auditory Displays i) Why? :Advantages/Disadvantages of Audio Presentation ii) When? :Environment and Task Factors iii) How? :Tones, Speech, etc. a) Discriminability b) Spatial Auditory Displays	1545-1645
Summary/Wrap-up		1645-1700