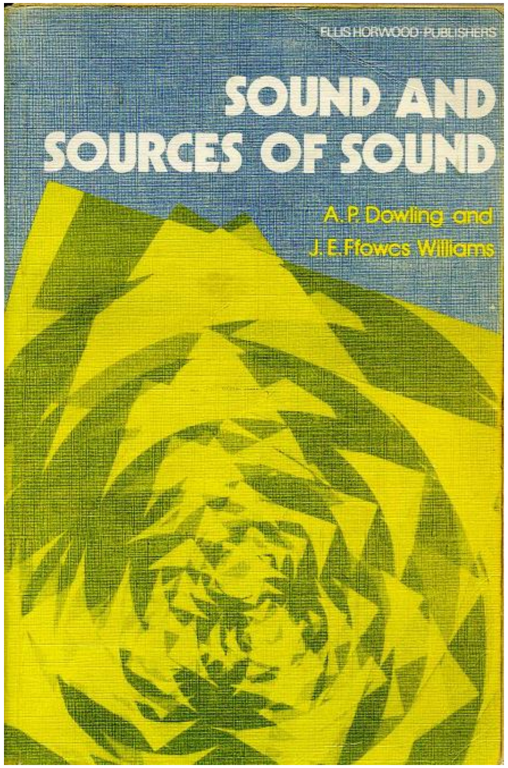
NOISE ENGINEERING

(Year 2019)

- Prof. Soogab Lee
  http://aancl.snu.ac.kr



- Time: Mon./Weds. 15:30-16:45
- Place: Blg. 301- Rm.306
- Office hour: Mon./Weds. 16:45-17:15
- T.A.: Jonghui Kim(880-7384)

PART I. Introduction of Acoustics

PART II. Basic Theory of Aero-acoustics

PART III. Computational Aeroacoustics

- Introduction to Computational Aeroacoustics
- Hybrid Techniques
  - Aeroacoustics of Rotating Machinery: Panel Method + Time-Domain Acoustic Analogy
  - Aeolian Tone: CFD + Acoustic Analogy
  - Aeroacoustics of High-speed Train: CFD + Kirchhoff Method
- Direct Flow-Acoustics Simulation
  - Trailing-Edge Noise: Acoustic-Viscous Splitting Methods
  - Twin-Cylinders : Immersed Surface Dipole Model
  - Turbo-Fan Engine Noise
  - Aeolian Tone: CAA

PART IV. Noise Evaluation & Control

- Basic Theory of Sound Absorbing Material and Its Application
- Noise Measurement & Experimental Method
- Active Noise Control
- Sound Quality
- Environmental Noise Assessment
- Human Response to Noise

PART V. Some Illustrative Applications

- Aerospace Science
- Mechanical Science
- Naval & Ocean Engineering
- Human Perception & Response
- Environmental Engineering
- Medical Application

❖ General overview

- Wheel of Acoustics (Lindsay, 1964)

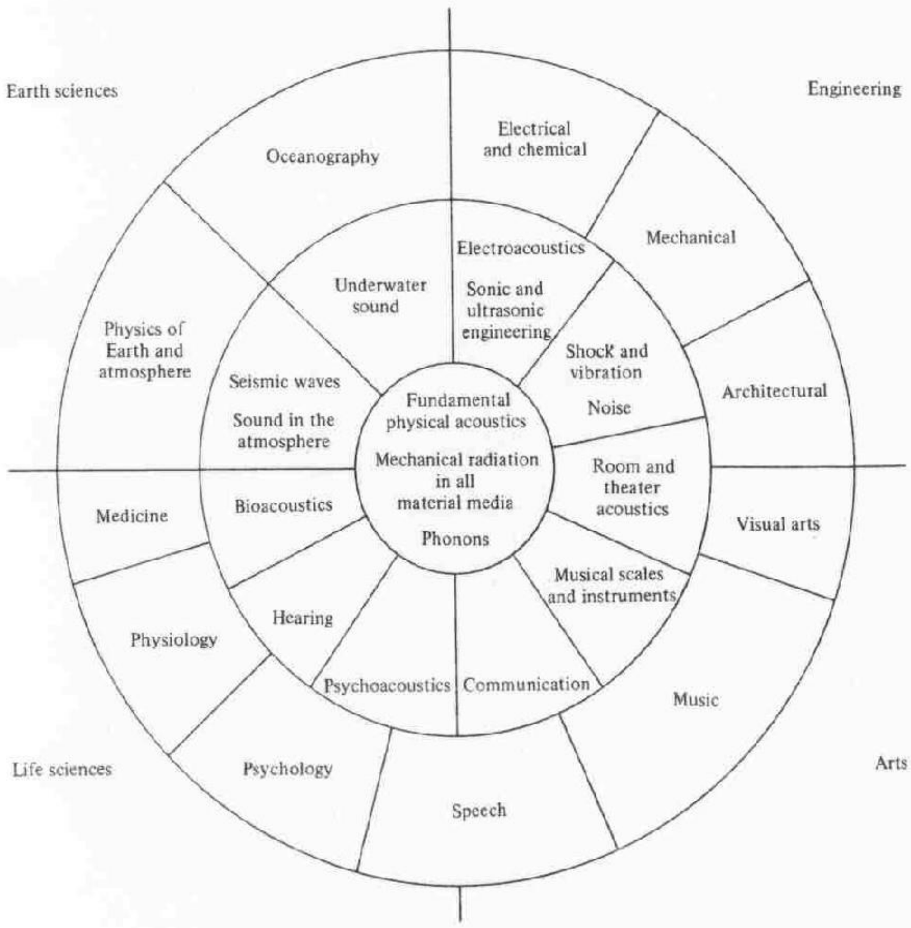
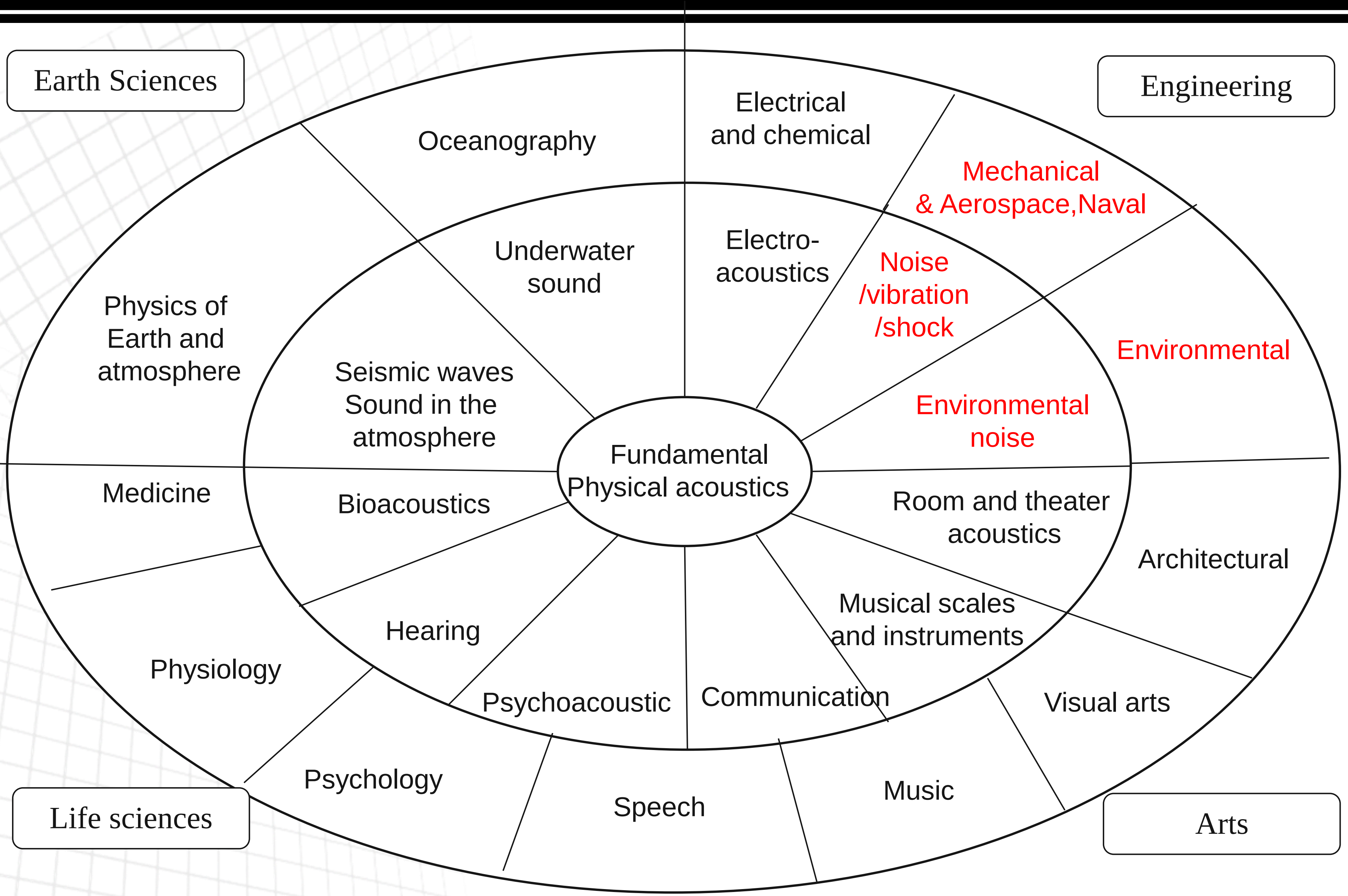


Figure 1-1 Circular chart illustrating the scope and ramifications of acoustics. [*Adapted from R. B. Lindsay, J. Acoust. Soc. Am.*, **36**:2242 (1964).]

Modified(from Linsay's) Wheel of Acoustics



❖ Acoustics in 19th Century

- Stokes and Rayleigh was the subject's greatest figures
  - Vibration string
  - Organ pipe
- The sounds they were interested in were generally pleasant.
- Nowadays most of the sounds of engineering interest are unpleasant, there being a large research effort concerned with the sound generated by Transportation vehicle and Machinery, etc.

❖ Modern-day Acoustics (Scopes of Acoustics)

- **Architectural Acoustics**


- Musical Acoustics
- Physiological acoustics :
  - Hearing disorder (Artificial Cochlea)
  - Effect of noise on human
- Psychological acoustics :
  - Loudness
  - Mental stress & disease
- Environmental noise :
  - Transportation noise, Shooting noise
  - Annoyance, Sleep disturbance
  - School-room noise

❖ Modern-day Acoustics (Scopes of Acoustics)

- Transportation noise :
  - Aircraft (Airplane, Helicopter, etc.)
  - (High Speed) Trains, Automobiles
  - Propeller, Rocket
- Industrial noise :
  - Turbo-machinery (Compressor, Turbine, etc.), Fan
  - Silencer
  - Combustion noise & Instability
- Underwater acoustics :
  - Submarine, Ships
  - Propulsion, Torpedo, Sonar
  - Long-range propagation

❖ Modern-day Acoustics (Scopes of Acoustics)

- Infrasound :
  - Vibration coupling
  - Effect on Human
  - Artillery
  - Seismic wave
- Ultrasonics :
  - Medical diagnostics
  - Structural integrity
- Active noise control :
  - Duct application
  - 3-D application
  - Signal processing

Classification by Sources

- Structure-borne Noise : Vibro-acoustics
- Airborne Noise : Aeroacoustics
- Liquid-borne Noise : Hydro-acoustics

Computational Aeroacoustics (CAA)

- Broad Definition :
  - Hybrid methodology (CFD + acoustic module)
- Narrow Definition :
  - Direct calculation of sound generation and propagation using high-order schemes (low dispersion)

❖ The Nature of Sound

- Sound propagates as a wave
  - 340 m/sec in air
  - 1500 m/sec in water

- Sound transports energy with it, and vibrates our eardrums

- Audible range
  - 20 ~ 20,000 Hz (cycles/sec)

- Sensitive range
  - 1000 ~ 5000 Hz

❖ The Nature of Sound

- Sound source supplies energy (Acoustic power)
  - Human whisper : 10^{-10} watts
  - Human shout : 10^{-5} watts
  - Large jet transport : 10^{5} watts

    $= 10^{-5}$watts $\times$ 10^{10}(world population)
  - Rocket launch : 10^{7} watts

  - Total acoustic energy during an exciting baseball game

    = energy for frying an egg !! (<u>acoustic energy is usually small</u>)

❖ Characteristics of Sound

- Sound waves have several key attributes
  - Compressible phenomenon
  - Very small wave amplitude, typically $p'/p_0 < 10^{-4}$

- Sound waves carry only a tiny fraction of the energy contained in the mean flow (very low acoustic efficiency)

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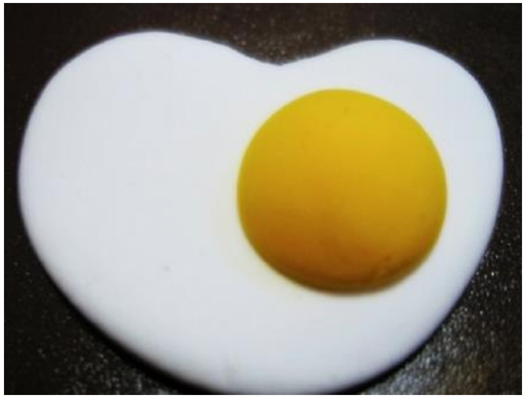


❖ The Nature of Sound

- Sound is a linear motion
- When a sound wave propagates, it disturbs the fluid from its mean state.
  - $p = p_0 + p'(\boldsymbol{x}, t)$
  - $\rho = \rho_0 + \rho'(\boldsymbol{x}, t)$
  - $\boldsymbol{v} = \boldsymbol{v}(\boldsymbol{x}, \mathrm{t})$
- Viscosity is unimportant in sound waves
  - Stress by pressure $\gg$ Stress by viscosity
  - Ratio of two stress = Reynolds number = $2\pi c\lambda/\nu = \omega\lambda^2/\nu$
  - If long distance propagation is involved, viscosity can be important (after the wave travels about $\omega\lambda^2/\nu$ wavelengths)

❖ The Nature of Sound

- Sound waves are classified as
  - longitudinal waves : a local vibration in gas or liquid
  - transverse waves : string vibration
  - water surface wave (has both longitudinal & transverse components)

- Simple Harmonic Waves
  - Speed(c), Frequency(f), Period(T), Frequency in radian(ω)
  - Wave number(k), Wave length(λ), Particle velocity(u)
  - $T=1/f$, $\lambda=cT=c/f$
  - $\omega=2\pi f=2\pi/T$, $k=\omega/c=2\pi f/c=2\pi/\lambda$
  - $\boldsymbol{u}=p'/\rho_0 c$

❖ Units of Noise

- Description of Sound Strength
  - Power : $W = dE/dt$ (watts)
  - Intensity : $\boldsymbol{I} = dW/d\boldsymbol{A}$ (watts/m^2)
  - Sound energy density

- Sound Power Level (PWL)
  - taken the log scale due to enormous range

$$\mathrm{PWL} = 10\log_{10}\left(\frac{\text{sound power output}}{10^{-12}\ \text{watts}}\right)$$

$$= 10\log_{10}\left(\text{sound power in watts}\right) + 120\,\text{dB}$$

❖ Units of Noise

- Sound Pressure Level (SPL)

$$\text{SPL in dB} = 20\log_{10}\left(\frac{p'_{rms}}{0.0002\,\mu\text{bar}}\right)$$

$$= 20\log_{10}\left(\frac{p'_{rms}}{2\times10^{-5}\,\text{N/m}^2}\right)$$

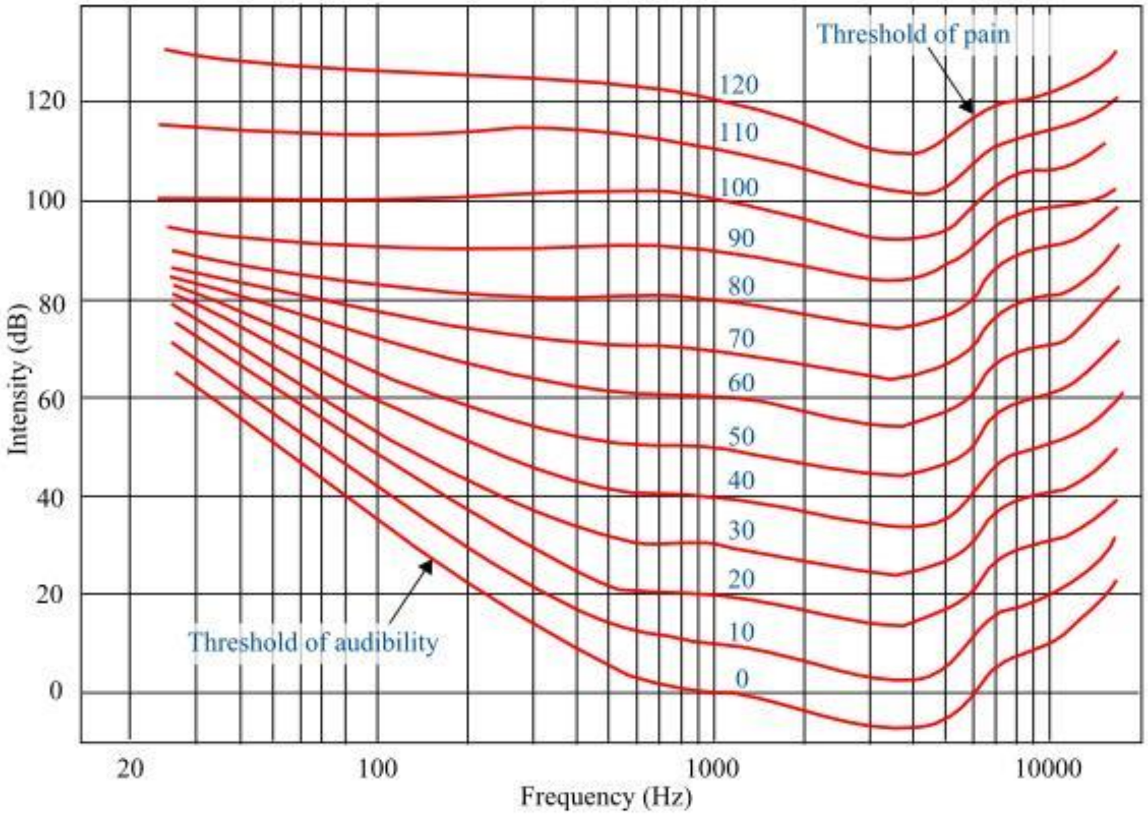
  - 1 atm pressure fluctuation = 194 dB
  - Threshold of pain = 130~140 dB ☞ $p'/p_0 \sim 10^{-3}$
  - Threshold of hearing = 0 dB ☞ $p'/p_0 \sim 10^{-10}$
  - P_{ref} = threshold of hearing

- Sound Intensity Level(IL)
  - IL (L_I) = 10 log10(I/I_{ref}) in dB where $I_{ref} = 10^{-12}$ watts/m^2

❖ Subjective Units of Noise

- Loudness Level (phons)

  : defined as loud as a pure tone of frequency 1kHz



❖ Subjective Units of Noise

- Loudness Level (sones)

  : linear measure of loudness (DL_p=40, DL_s=1)

$$LL_s = 2^{(LL-40)/10}$$

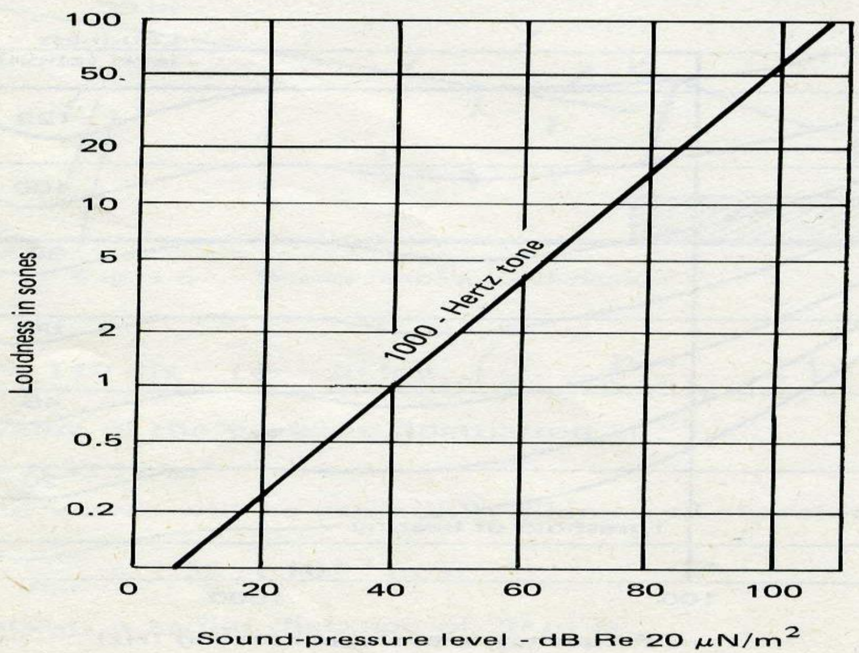
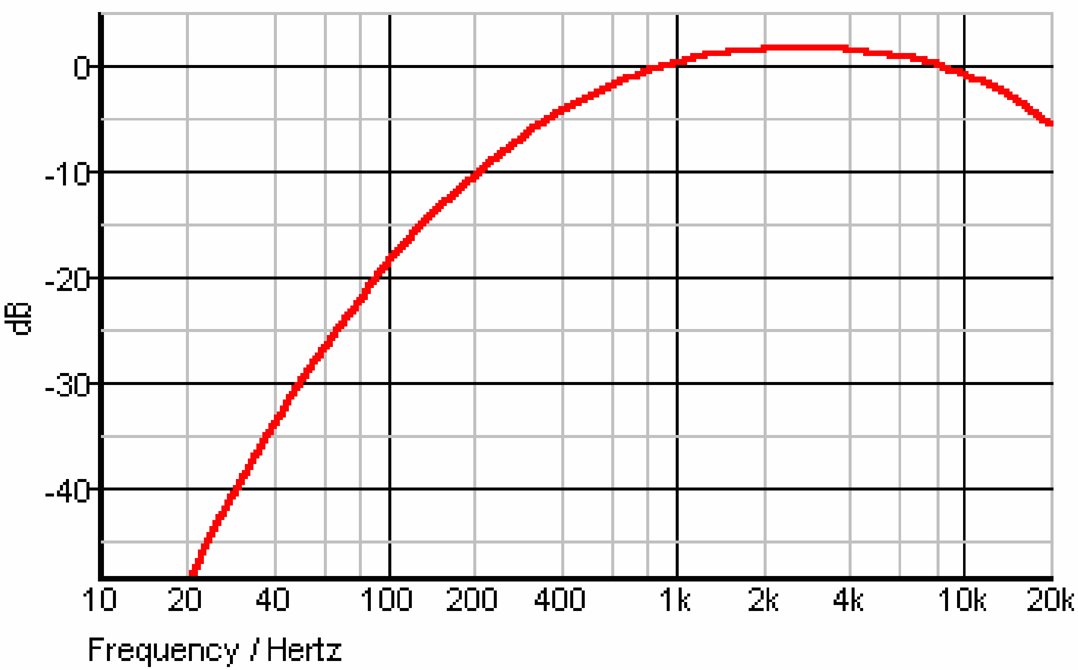


Fig. 1.8 — Loudness of a 1 kHz tone.

❖ Subjective Units of Noise

- 'A-weighting' Sound Pressure Level (dBA)
  - weighting SPL in each frequency level by taking into account the ear's sensitivity. Internationally accepted.

(Note) 'B & C weightings' are rarely used.



❖ Subjective Units of Noise

- Directivity Index (DI) & Q-factor

$$DI = SPL_i - \overline{SPL} = 10\log_{10} Q$$

- Perceived Noise Level (PNdB) - unit:(noy)
  - mainly for aircraft noise by taking account for high frequency components of jet noise; use different weighting; typically 12-16 dB higher than dB_A

- Effective Perceived Noise Level (EPNL)
  - weighting the pure tones in noise signal (turbo-machinery)

❖ Subjective Units of Noise

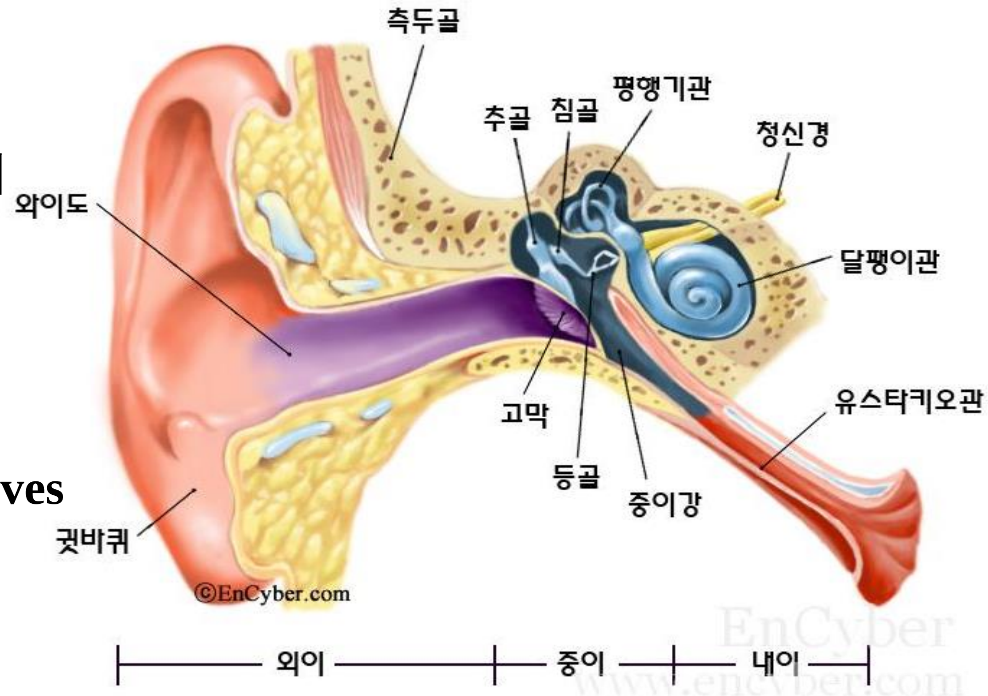
- Total Noise Exposure Level (TNEL)
  - consider the number of aircraft.

- Equivalent Continuous Perceived Noise Level (ECPNL)
  - the average of EPNL

- Weighted ECPNL (WECPNL)
  - taking account for the effect of night time. (add 10dB)

❖Structure of Ear

1. 외이(外耳) : collecting sound
   - 외이도 : 직경 약 10mm, 길이 약 27mm로 일종의 공명기 역할. Resonant frequency는 3kHz.

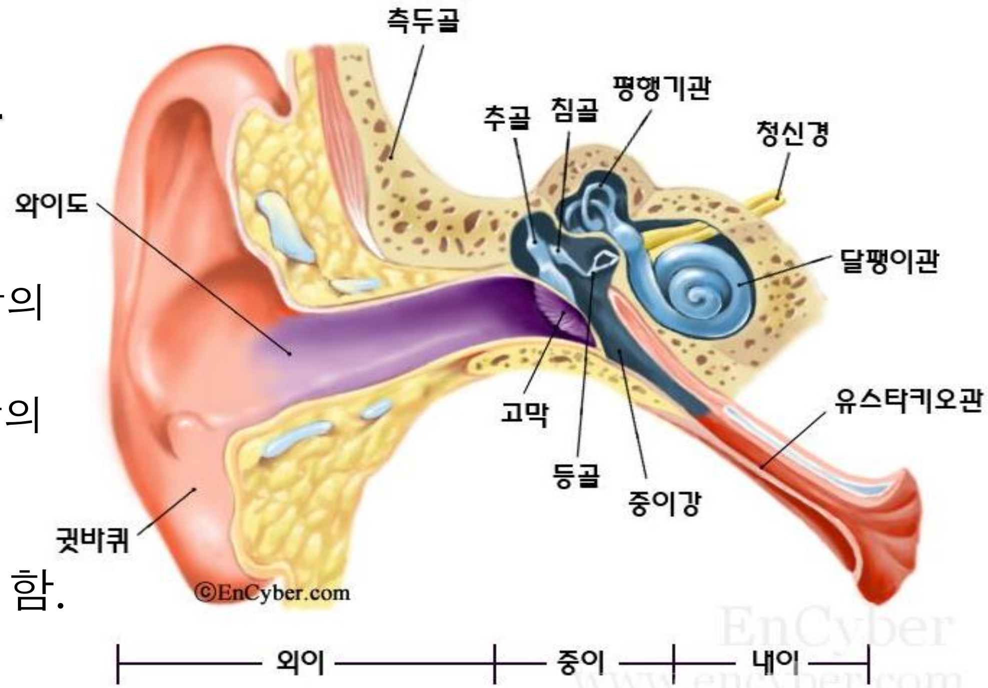


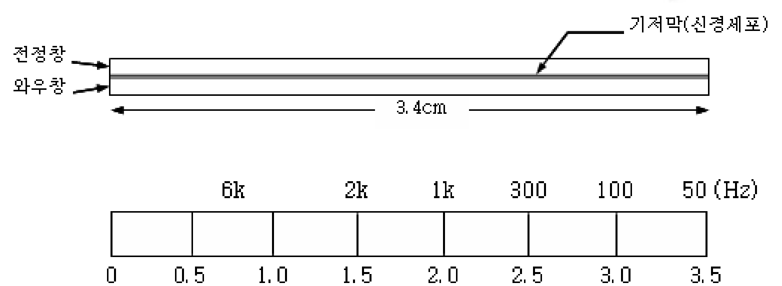
2. 중이(中耳) : Amplification of waves
   - 고막 : 두께 약 0.1mm, 실효면적 약 0.3~0.5cm2
   - 청소골 : 망치뼈, 모두뼈, 등자뼈로 구성되어 고막에 전달된 음압을 약 20배 증폭

❖ Structure of Ear

3. **내이(內耳) : 소리를 분석하고 분석된 소리를 뇌로 전달**

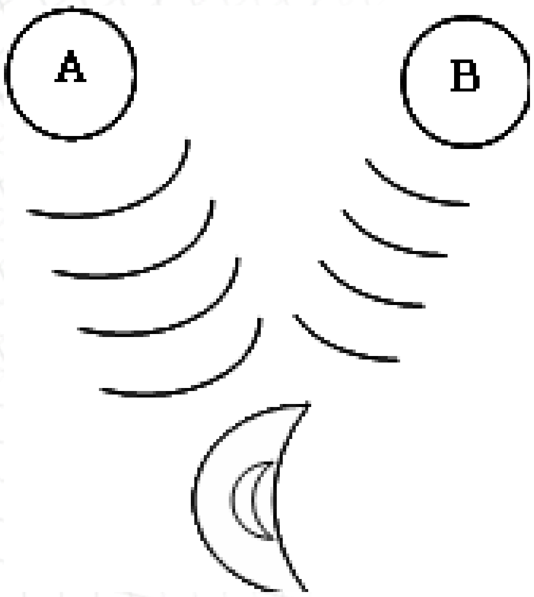
- 달팽이관
  - Amplitude of sound : 기저막의 진동 크기
  - Frequency of sound : 기저막의 진동 위치
- Eustachian tube : 기압조정, 목과 연결, 진동을 용이하게 함.
  Large vibration은 근육이 수축하여 damping

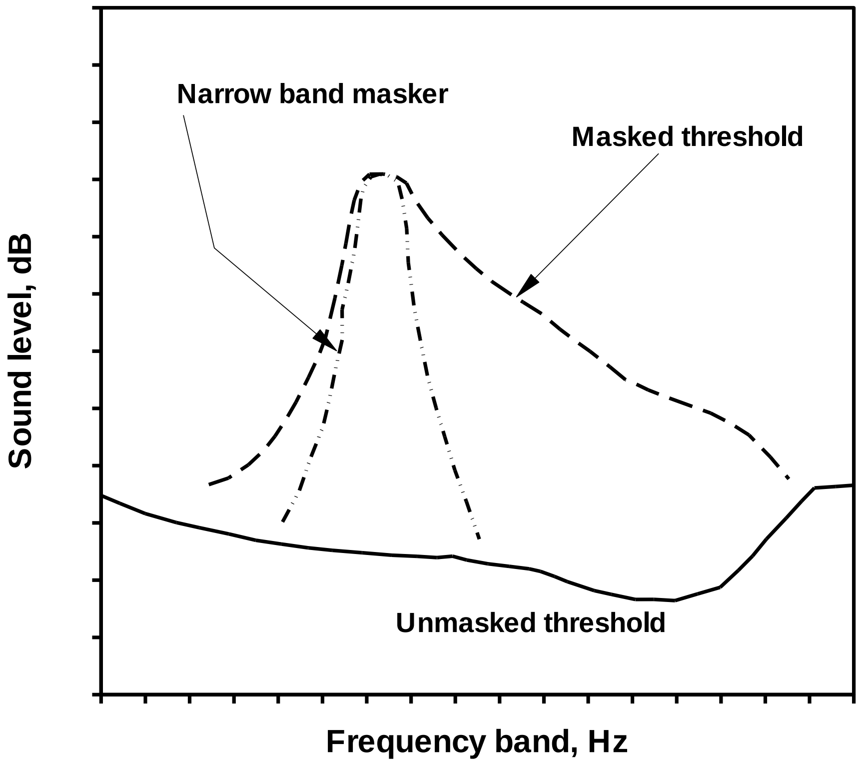




❖ Masking effect

- 'B' sound is masked by sound 'A'
  → Physiological effect by increasing the threshold of hearing

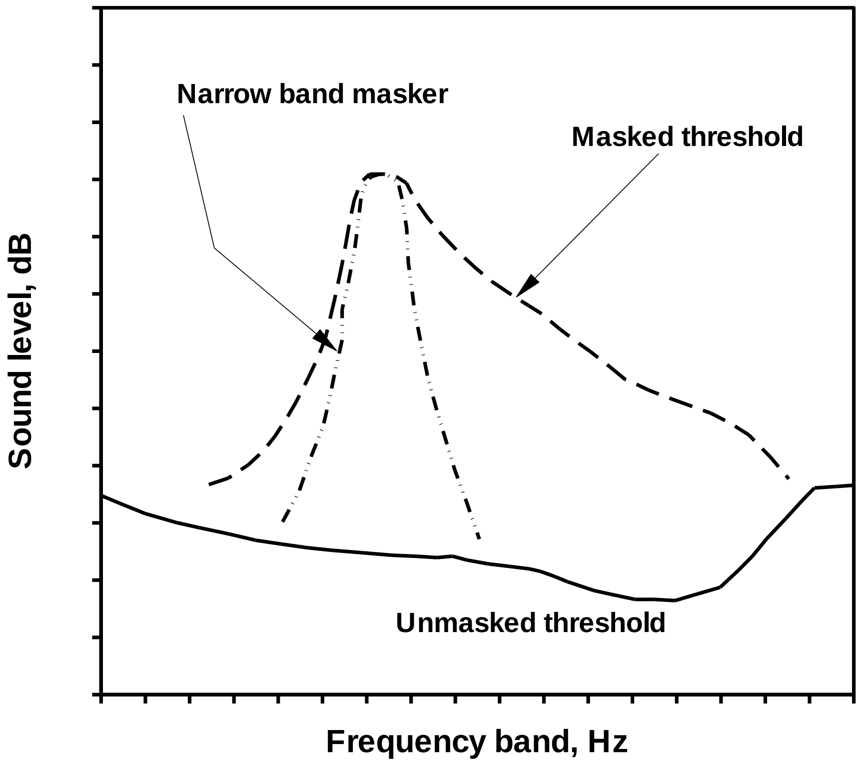




❖ Masking effect

- Generally masking has a bad effect. If you utilize BGM(Back Ground Music), you can mask the noise.

- If a person stays too long at very silent place, he/she will become unstable psychologically.
  → A little bit of noise is good for human



❖ Influence of Noise

- Definition

  : Noise is <u>unpleasant sound</u>

- TTS & PTS : serious at 3-6 kHz
  - TTS (noise-induced temporary threshold shift):
  - PTS (noise-induced permanent threshold shift):
  - Measurement of hearing level : Audiometer
  - ISO standard : 10-15 dB normal, 25dB or higher PTS
- NER (Noise Exposure Rating)
- SIL (Speech Interference Level)

Influence of Noise

- Infrasound (<16 Hz)
  - Tides, earthquakes, thunder, AirCon, Jet Aircraft ...
  - Make people sleepy & tired, Potential weapon
- Ultrasound (>20kHz)
  - Jet engine, High-speed drill, Washing machine
  - Medical Purpose, should be < 105 dB (EPA)
- Sonic Boom
  - N-wave, Boom carpet, Rising time (0.1~16 ms)
  - Should be less than 55 dB (EPA)

Three-dimensional wave equation

- **Sound waves are classified as**
  - Longitudinal waves – a local vibration in gas or liquid
  - Transverse waves – string vibration
  - Water surface wave (has both longitudinal & transverse components)