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ME 41300 Noise Control
Spring 2021
Final Examination
Date: Wednesday, 5 May 2021
Time: 1:00 pm - 3:00 pm

INSTRUCTIONS

This is a closed book examination. All equations will be provided.

There are 5 (**FIVE**) questions in this examination paper. Answer **all** questions. **Each** question carries 20 points.

You are advised to read all questions first before you attempt the Exam paper.

Turn off your cell phone and leave it in your backpack. Make sure all computers you brought are in your backpack. Your backpack is not to be opened during the examination.

Please remember that in order for you to obtain maximum credits for a problem, the solution must be clearly presented, i.e.

- any assumptions used to arrive your solutions must be clearly stated,
- wherever appropriate, clearly labeled diagrams must be drawn.
- units must be clearly stated as part of the answer.

If the solution does not follow a logical thought process, it will be assumed in error.

Post Exam Instructions

Exam Period Over

1. Completion of Exam at 3:00 pm: Once the exam period is over, you need to stop writing immediately. Please respect the exam deadline. No Chat message and discussions with others.

2. Scan Exam – Using your phone, please scan your exam paper.

3. Upload the Exam to Gradescope (ME 413 Final Exam)– Please go to the Gradescope and upload your exam solutions. Assign the pages for Problems 1, 2, 3, 4 and 5. You do not need to assign the cover page. This will enable me to grade the exam quicker and get it back to you. I encourage you to check to make sure your exam properly uploaded ALL of your exam pages. Remember you only have 20 minutes to scan and upload your exam.

4. You may leave after you upload your exam paper to Gradescope. Please leave your exam paper on your desk before you go.

5. If you finish your exam earlier, let me know before you start scanning your exam paper. Follow the Step 1 to 4 after you have my approval.

Name: ______________________

Problem 1 – Fundamentals of Vibration and Acoustics

(a) Describe, with the aid of a sketch or relevant equations when necessary, each of the following:
   (i) spring force, excitation, natural frequency and resonance of a vibratory system;
   (ii) kinetic energy and pressure (potential) energy of a one-dimensional planar waves. **(4 points)**

(b) A table has a vertical sinusoidal motion with constant frequency 15 Hz. What is the largest **velocity amplitude** that the table can have, if an object on the table is to remain in contact?
You may take the gravitational constant g as 9.81 m s^{-2}. **(4 points)**

(c) A pure tone of sound has a frequency of 165 Hz and an amplitude of 2.5×10^{-5} Pa, determine
   (i) the root mean square pressure of the signal, and
   (ii) the **wavelength** and **wave number** of the sound. You may take speed of sound in air as 340 m/s. **(4 points)**

(d) According to a noise measurement, the root-mean-square acoustic pressure at a distance of 10 m from an engine running at full open throttle is 1.8×10^{-3} Pa.
   (i) What is the mean acoustic power output of the automobile?
   (ii) What is the sound power level of the source? **(8 points)**

You may assume all sound waves incident on the ground are absorbed and that the sound field is omni-directional, *i.e.* the same in all direction. Take the acoustic impedance, ρc to be 413 MKS rayls. You may also assume the sound radiated from a point source may be treated as plane waves, i.e. the pressure (rms) and particle velocity (rms) are related by $p_{rms} = \rho c u_{rms}$. The following formulas are also found useful:

$$L_p = 10\log\left(\frac{p_{rms}^2}{p_{ref}^2}\right); \quad SWL = 10\log\left(\frac{W}{W_{ref}}\right)$$

a) **Solutions**

i) Spring force is a force that is acting on a system in a direction to return to it's equilibrium state.

Excitation is a force applied to a system causing it to leave equilibrium

Natural frequency: The frequency that a system will tend to vibrate at naturally.

Resonance: The additional displacement caused by oscillation at or near the natural frequency.

ii) Kinetic energy is energy due to the velocity of the particles in the wave.

Potential energy is the energy due to the pressure difference between the wave and ambient case.

b) $f = 15\,Hz$ $\quad \omega_n = 2\pi f = 94.25\,rad/s$ $\quad \omega_n = \sqrt{g/m}$

No velocity limit since no relation to force, $F=ma$

c) i) $f = 165\,Hz$ $\quad p = 2.5\times10^{-5}\,Pa$ $\quad P_{rms} = \frac{2.5\times10^{-5}\,Pa}{\sqrt{2}} = \boxed{P_{rms} = 1.77\times10^{-5}\,Pa}$

P. 1 Continue …

ii) $\lambda = \frac{c}{f} = \frac{340\,m/s}{165\,1/s} = \boxed{\lambda = 2.06\,m}$ $\quad k = \frac{2\pi}{\lambda} = \boxed{3.05\,rad/m = k}$

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P. 1 Solutions

d) $P_{rms} = 1.8 \times 10^{-3}$ Pa $\quad r = 10\,m \quad SWL = SPL + 11 + 20\log(r)$

$P = \sqrt{2} \cdot P_{rms} = 2.55 \times 10^{-3}$

$SPL = 20\log\left(\frac{2.55\times10^{-3}\,Pa}{2\times10^{-5}\,Pa}\right) = 42.1\,dB$

$SWL = 42.1\,dB + 8\,dB + 20\log(10) = \boxed{SWL = 70.1\,dB}$

$W = 10^{(73.1/10)} \cdot 1\times10^{-12}\,W = \boxed{W = 2.04\times10^{-5}\,W}$

e)

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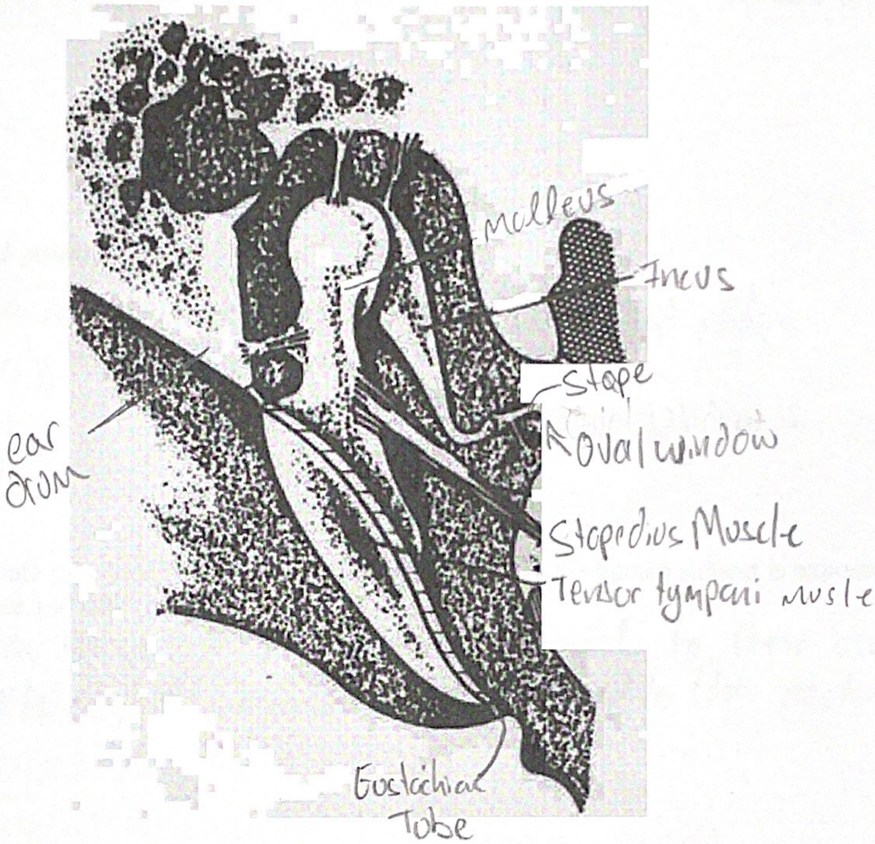
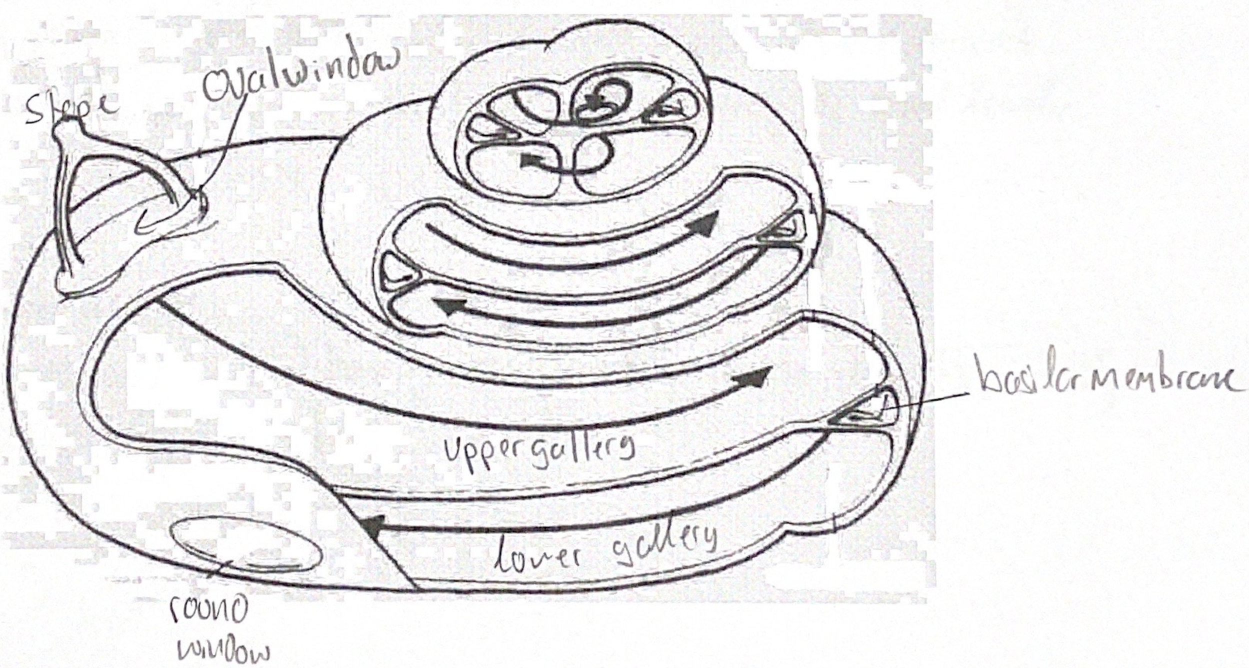
Problem 2

(a) Identify the following terms in the middle ear shown in the diagram below **(4 points)**:
malleus, incus, stape, oval window, stapedius muscle, tensor tympani muscle, tympanic membrane (ear drum), Eustachian tube.



(b) Identify the following terms in the cochlea shown in the diagram below **(3 points)** :
oval window, round window, scala vestibule (upper gallery), scala tympanic (lower gallery), basilar membrane, stape



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(c) What are ossicles? Explain their functions. **(4 points)**

The ossicles are the 3 bones in the middle ear (Malleus, Incus, Stape).
They transmit vibrations from the ear drum to the oval window/cochlea.

(d) What is acoustic reflex? **(2 points)**

The acoustic reflex is the mechanism of the ossicles that allows reduction of hearing loss to loud Sounds.

(e) How can the ossicles operate to reduce permanent hearing damages when the human subject is exposed to a short and intense sound pressure over 140 dB? **(2 points)**

The ossicles can move in a direction normal to their usual motion to reduce the intensity of vibrations being transmitted to the cochlea.

(f) Explain Temporary threshold shift. **(3 points)**

Temporary threshold shift is a non-permanent loss of hearing sensitivity, usually due to exposure to loud sounds, like a concert.
It changes which frequencies can be heard and sensitivity to sound levels.

(g) What is presbyscusis? **(2 points)**

Presbycusis is age related hearing loss, usually people lose the ability to hear higher frequencies first.

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Problem 3

(a) Explain the differences between
   (i) low pass, high pass and band pass filters,
   (ii) white and pink noise sources. **(4 points)**

(b) What are the lower band and upper band frequency of the (i) octave band, and (ii) one-third octave band with the center frequency of 4000 Hz? What are their corresponding bandwidths of the octave band and one-third octave band? **(6 points)**

(c) In a day shift, a worker spends an hour in a boiler room where the A-weighted noise level is 93 dBA, 2 hours in a workshop where the A-weighted noise level is 91 dB.
   (i) According OSHA 1970, how long (in hours) of the remaining work-day can the worker spend in a machine room which has the A-weighted noise level of 90 dB? If the machine room has been modified to reduce the A-weighted noise level to 88 dB, how long can the worker stay in the room?
   (ii) According to OSHA-HCA 1981, how long of the remaining day can the worker spend in the modified machine room in order to avoid having to implement a hearing conservation program for the worker? **(10 points)**

1. Criteria for Engineering or Administrative Controls
Feasible administrative or engineering controls shall be utilized if noise dose D is greater than 1.0 in accordance with the following equation:

$$D = \left(\frac{C_1}{T_1}\right) + \left(\frac{C_2}{T_2}\right) + \left(\frac{C_3}{T_3}\right) \dots + \left(\frac{C_N}{T_N}\right) \qquad \text{(F-3)}$$

where:
D = Daily noise dose (must not exceed unity)
C = Actual exposure time at a given noise level
T = Permissible exposure time at that level in accordance with the table below.

Duration Per Day, Hr	Permissible Exposure "Slow" Response, dBA
8	90
6	92
4	95
3	97
2	100
1.5	102
1	105
0.5	110
0.25 or Less	115

Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

2. OSHA Criteria for Hearing Conservation Programs
Employers shall administer continuing, effective hearing conservation programs wherever employee noise exposures equal or exceed an 8-hour time weighted average of 85 dBA or, equivalently, a dose of 50% measured according to the following equation:

$$D = 100\left[\left(\frac{C_1}{T_1}\right) + \left(\frac{C_2}{T_2}\right) \dots \left(\frac{C_N}{T_N}\right)\right] \qquad \text{(F-6)}$$

where:
D = Workday dose in percent
1,2,3 = Periods of exposure to different dBA levels
C = Actual exposure time at different levels
T = Permissible exposure time at a given level in accordance with the following table.

A-weighted Sound Level, L (dB)	Reference Duration, T (hr)	A-weighted Sound Level, L (dB)	Reference Duration, T (hr)
80	32.0	92	6.2
81	27.9	93	5.3
82	24.3	94	4.6
83	21.1	95	4.0
84	18.4	96	3.5
85	16.0	97	3.0
86	13.9	98	2.6
87	12.1	99	2.3
88	10.6	100	2.0
89	9.2	101	1.7
90	8.0	102	1.5
91	7.0	103	1.4

Solutions

a) i) low pass filters pass all frequencies below a set threshold.
High pass filters pass all frequencies above a threshold.
Band pass filters pass all frequencies in a range between an upper and lower threshold.

ii) White noise has constant spectral energy across the frequency spectrum.
Pink noise has diminishing spectral energy as frequency increases (-3dB per doubling

b) i) $f_c = 4000\,Hz$ $\quad f_2 = f_c \cdot \sqrt{2} = \boxed{5656.9\,Hz = f_2}$ $\quad F_1 = \frac{f_c}{\sqrt{2}} = \boxed{f_1 = 2828.4\,Hz}$

P. 3 Continue …

$B.W = f_2 - f_1 = \boxed{B.W. = 2828.5\,Hz}$

ii) $f_2 = f_c \cdot 2^{1/6} = \boxed{4489.8\,Hz = f_2}$ $\quad F_1 = f_c / 2^{1/6} = \boxed{3563.6\,Hz = f_1}$ $\quad \boxed{B.W = 926.2\,Hz}$

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P. 3 Solutions (Continued)

c) $L_1 = 93\,dBA \quad C_1 = 1\,hr \quad T_1 = 5.3\,hr$

i) $L_2 = 91\,dBA \quad C_2 = 2\,hr \quad T_2 = 7\,hr$

$L_T = 90\,dBA \quad C_T = ? \quad T_3 = 8\,hr$

$$\frac{1\,hr}{5.3\,hr} + \frac{2\,hr}{7\,hr} + \frac{C_T}{8\,hr} = 1$$

$$\frac{C_T}{8} = 0.526 \Rightarrow \boxed{C_T = 4.20\,hr} \text{ for } L_T = 90\,dBA$$

ii) if $L_T = 88\,dBA \quad T_3 = 10.6\,hr$

$$\frac{C_T}{10.6} = 0.526 \Rightarrow \boxed{C_T = 5.6\,hr \Rightarrow 5\,hr \text{ (in 8 hour work day)}}$$

iii) $$\frac{1\,hr}{5.3\,hr} + \frac{2\,hr}{7\,hr} + \frac{C_T}{10.6\,hr} = 0.5 \Rightarrow \frac{C_T}{10.6\,hr} = 0.026$$

$$\Rightarrow \boxed{C_T = 0.27\,hrs}$$

without hearing conservation

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Problem 4

(a) With the aid of a block diagram, explain the key components found in a typical sound level meter used for noise measurements. **(3 points)**

(b) After you have completed a noise survey, you need to provide a sketch of the measurement site showing applicable dimensions. You also need to indicate the locations of microphone and object being measured. List all other information that will be required in the measurement report. **(3 points)**

(c) In the assessment of industrial noise, measurements of ***specific*** **noise level**, ***ambient*** **noise level**, ***residual*** **noise level** and ***background*** **noise level** are needed. Distinguish between these noise levels. **(4 points)**

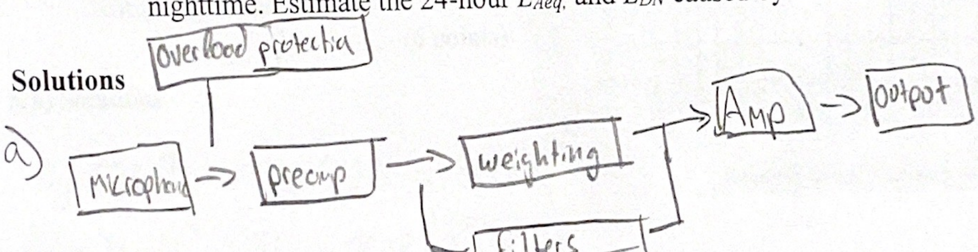
(d) A residential building is located near a car wash facility. The background noise levels are 50 dB(A) in the daytime (7:00 am to 10:00 pm) and 35 dB(A) in the nighttime (10:00 pm to 7:00 am next morning). The car wash, which takes 2 minutes to complete, generates a noise level 55 dB(A). Calculate the daytime and nightime hourly L_{A10}, L_{A50}, L_{A90} and L_{Aeq} when

(i) there are 3 carwashes every hour;
(ii) there are 10 carwashes every hour;
(iii) there are 20 carwashes every hour.
(iv) Suppose that there is a total of 120 carwashes during the daytime and 15 carwashes during the nighttime. Estimate the 24-hour $L_{Aeq.}$ and L_{DN} caused by the carwash facilities.

(10 points)

Solutions

a)



b) The date of observation, Specifications of equipment being used,

c) Specific noise: Noise level of the source of interest
Ambient noise: Noise level of everything (residual + source)
Residual noise: Noise level without the specific noise/source of interest
Background noise: Noise level exceeded 90% of the time of measurement (L_{A90})

d) $L_{A90} = 50\,dBA$ (Day) $T_D = 15\,hr$
$L_{A90} = 35\,dBA$ (Night) $T_N = 9\,hr$

$L_S = 55\,dB$ $T_S = 2\,min$
$L_D = 55 \oplus 50 = 56.2\,dBA = L_P$
$L_N = 55 \oplus 35 = 55.0\,dBA$

i)

	Day	Night
L_{A10}	56.2dBA	55dBA
L_{A50}	50dBA	35dBA
L_{A90}	50dBA	35dBA
L_{Aeq}	51.2dBA	45.4dBA

$$L_{AeqD} = 10\log\left(\frac{6\cdot 10^{5.62} + 54\cdot 10^{5.0}}{60}\right) = 51.2\,dBA$$

$$L_{AeqN} = 10\log\left(\frac{6\cdot 10^{5.5} + 54\cdot 10^{3.5}}{60}\right) = 45.4\,dBA$$

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Extra Page for solutions

ii) 10 car wash => 20min of carwash

$L_D = 56.2$ $L_N = 55$
$L_{DBg} = 50$ $L_{NBg} = 35$

	Day	Night
L_{A10}	56.2 dBA	55 dBA
L_{A50}	50 dBA	35 dBA
L_{A90}	50 dBA	35 dBA
L_{Aeq}	53.1 dBA	50.3 dBA

$$L_{Aeq}D = 10\log\left[\frac{20\cdot 10^{5.62} + 40\cdot 10^{5.0}}{60}\right] = 53.1\,dBA$$

$$L_{Aeq}N = 10\log\left[\frac{20\cdot 10^{5.5} + 40\cdot 10^{3.5}}{60}\right] = 50.3\,dBA$$

iii) 20 carwash = 40 min

	Day	Night
L_{A10}	56.2 dBA	55 dBA
L_{A50}	56.2 dBA	55 dBA
L_{A90}	50 dBA	35 dBA
L_{Aeq}	54.9 dBA	53.3 dBA

$$L_{Aeq}D = 10\log\left[\frac{40\cdot 10^{5.62} + 20\cdot 10^{5.0}}{60}\right] = 54.9\,dBA$$

$$L_{Aeq}N = 10\log\left[\frac{40\cdot 10^{5.5} + 20\cdot 10^{3.5}}{60}\right] = 53.3\,dBA$$

iv) 120 in day   15 in Night $15\cdot 2 = 30\,min = 0.5\,hrs$

$120 = 240\,min = 4\,hr$

$$L_{Aeq,24} = 10\log\left[\frac{4\cdot 10^{5.62} + 11\cdot 10^{5.0} + 0.5\cdot 10^{5.5} + 8.5\cdot 10^{3.5}}{24}\right]$$

$$\boxed{L_{Aeq,24} = 50.9\,dBA}$$

$$L_{Aeq,D} = 10\log\left[\frac{4\cdot 10^{5.62} + 11\cdot 10^{5.0}}{15}\right] = 52.66\,dBA \approx 52.7$$

$$L_{Aeq}N = 10\log\left[\frac{0.5\cdot 10^{5.5} + 8.5\cdot 10^{3.5}}{9}\right] = 43.1\,dBA$$

$$L_{DN} = 10\log\left[\frac{15\cdot 10^{5.27} + 9\cdot 10^{4.31}}{24}\right] = \boxed{50.9\,dBA = L_{DN}}$$

$L_{DN} = L_{Aeq,24}$?

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Problem 5

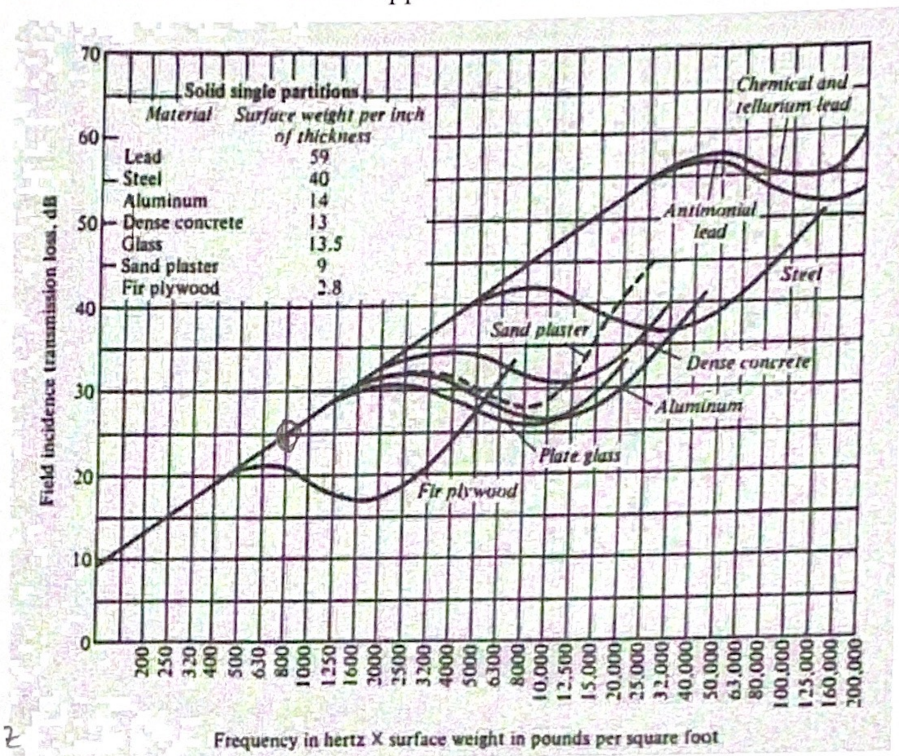
(a) Define the sound transmission coefficient and transmission loss as applied to the sound insulation of a partition.

A door, which has dimensions of 4 feet wide and 7 feet high, has transmission loss of 15 dB at 800 Hz. It is installed in a sand plaster wall of 2-inch thick with 25 feet wide by 10 feet high. You may use the attached chart to determine the transmission loss of the sand plaster wall at 800 Hz. Estimate the sound transmission loss of the composite partition if:

(i) the door fits perfectly;

(ii) there is an air gap of 1.5 inch at the bottom of the door.

(6 points)



5(a) Solutions

$A_d = 28 ft^2$ $TL_D = 15 dB$ at 800Hz

$A_t = 250 ft^2$ $TL_{sp} = 25 dB$ at 800Hz

Total Area = $250 ft^2$ Door Area = $28 ft^2$

Wall Area = $250 - 28 = 222 ft^2$ $A_1 = 28 ft^2$ $A_2 = 222 ft^2$

a) $\tau = \frac{28 \cdot 10^{-1.5} + 222 \cdot 10^{-2.5}}{250}$ $TL = 10 \log(1/\tau)$

$\boxed{TL = 21.97 dB}$

i) Transmission loss is the loss of sound pressure through a partition. Transmission coefficient is related to how much sound passes through a partition. (coefficient is inverse to Transmission loss)

ii) air gap $\tau = 1$ $A_3 = 1.5 in \cdot 48 in = 72 in^2 = 0.5 ft^2$

$A_1 = 28 ft^2$ $A_2 = 221.5 ft^2$ $A_3 = 0.5 ft^2$

$\tau = \frac{28}{250} \cdot 10^{-1.5} + \frac{221.5}{250} \cdot 10^{-2.5} + \frac{0.5}{250} \cdot 10^{0} = 2.05$

$TL = 10 \log(1/\tau) \Rightarrow \boxed{TL = 20.8 dB}$

P. 5 Continued ...

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(b) The following figure shows the standard equal loudness contours which specify human binaural listening to the stimuli in a sound field.

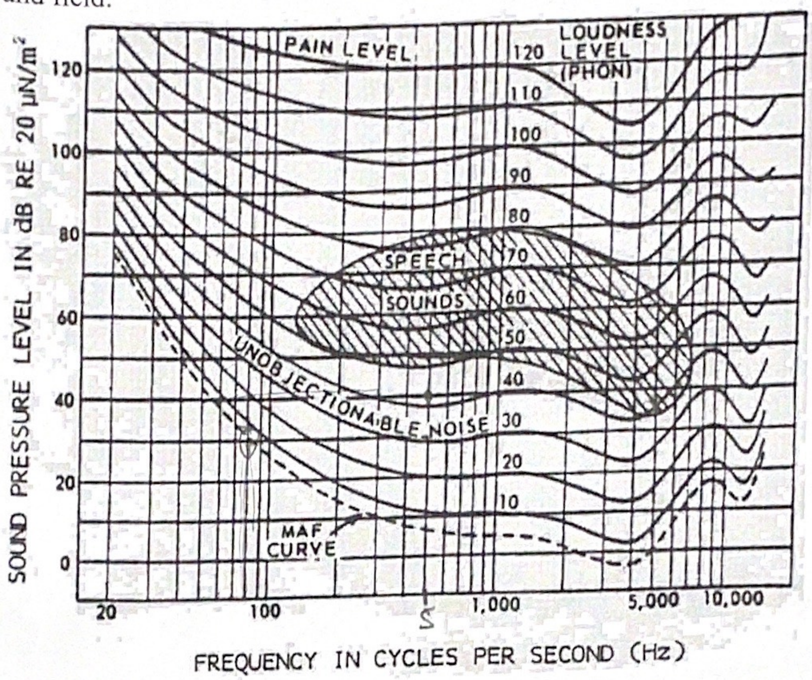

Figure P. 5: Equal loudness contours

(i) Explain the meaning of Minimum Audible Field (MAF) curve. A sound is played with pressure of 1.12×10^{-3} Pa. To be considered audible for normal hearing, what is the lowest frequency of this sound? Take P_{ref} = 2×10^{-5} Pa. **(2 points)**

(ii) At 500 Hz, a 40 dB tone sounds as equally loud as a 5 kHz tone. What is the dB level of that 5 kHz tone? What is the loudness and loudness level if the two pure tones play together? **(3 points)**

(iii) The spectrum of the background noise level in a workshop is given below:

Frequency / Hz	125	250	500	1000	2000	4000	8000
Noise / dB	56	54	57	61	59	60	50

1) What is the preferred speech interference level (PSIL) of the background noise? **(2 points)**
2) Find the A-weighted background noise level, and, then determine whether speech communication is possible over a distance of 8 feet in the workshop. Estimate the minimum distance where the normal communicating voice level is possible at this back ground noise level. **(4 points)**
3) Find the articulation index in the presence of the background noise in the workshop for the speaker locating at 1m from the listener. **(3 points)**

(Hint: See the Appendix at the back of the exam paper for the relevant charts and tables)

P. 5(b) Solutions

i) MAF is found from testing Audibility by frequency with speakers. it gives the minimum level at which frequencies can be heard.

$SPL = 20\log\left(1.12\times10^{-3}/2\times10^{-5}\right) = 35\,dB$ Minimum freq: 80 Hz

ii) Around 36 dB loudness level ≈ 40 Phon (for each) $LL_T = 10\log\left(10^{4}+10^{4}\right) = \boxed{LL_T = 43\,Phon}$

$S = 2^{(43-40)/10} = \boxed{1.23\ Sone = S}$

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P. 5(b) Solutions (Continued)

iii) $PSIL = (L_{500} + L_{1000} + L_{2000})/3$

1) $PSIL = \frac{57 + 61 + 59}{3} = \boxed{59\,dB = PSIL}$

freq	125	250	500	1000	2000	4000	8000
dB	56	54	57	61	59	60	50
dBA	39.9	45.4	53.8	61	60.2	61	48.9

Overall dBA

$L_A = 10\log\left[10^{3.99} + 10^{4.54} + 10^{5.38} + 10^{6.1} + 10^{6.02} + 10^{6.1} + 10^{4.89}\right]$

2) $\boxed{L_A = 65.9\,dBA}$

Maximum distance for Normal Communicating Level would be about 1.6 ft

Communication Possible at 8 feet with Raised/Very loud voice

3) A.I.: SL-NL · Weighting

freq		
250:	$(72 - 54)\cdot 18 =$	324
500:	$(73 - 57)\cdot 50 =$	800
1000:	$(78 - 61)\cdot 75 =$	1275
2000:	$(63 - 59)\cdot 107 =$	428
4000:	$(58 - 61)\cdot 83 =$	0
Sum		2827

$\frac{2827}{1000} \cdot 100\% = AI = 28.27\%$

$\boxed{\text{Articulation Index} = 28.27\%}$ (at 1m)