INCE-USA

Institute of Noise Control Engineering of the USA

INCE Business Office
9100 Purdue Road, Suite 200
Indianapolis, IN 46268

Phone: (317) 735-4063
Fax: (317) 280-8527

ibo@inceusa.org

INCE PROFESSIONAL EXAM STUDY GUIDE

Insitute of Noise Control Engineering

August 2010

Institute of Noise Control Engineers (INCE)
Professional Examination Information

TABLE OF CONTENTS

Institute of Noise Control Engineers (INCE)
Professional Examination Information

INTRODUCTION

This document provides information about the INCE Professional Exam including a description, hints for successful completion, how the exam is graded, a list of exam topics, bibliography, and sample problems. Passing the Professional Exam is an important step in becoming an INCE Board Certified member.

This guide is intended to help those taking the exam prepare successfully. If you have any further questions please contact the INCE business office.

EXAM DESCRIPTION

The INCE Professional examination is a two part test. The first part consists of short-answer questions in a closed book format. The second part consists of practical problems that require calculations in an open book format. The two parts will be administered during morning and afternoon periods with a 1 hour break for lunch.

During the four-hour morning exam, you will be given ten (10) short-answer questions and must complete all ten. You may not refer to any notes, computers, calculators, or references while taking this portion of the exam. Answers should be given in the space provided. Try to keep answers to within about three to five sentences. No formulas are allowed in the short-answer portion of the exam; although, you may write out relationships. For example, if you are describing the spring constant, k, "$k=mg/\delta$" would receive no credit, but "*In evaluating the deformation of a spring, k is the ratio of the gravitational force acting on a mass to the spring's static deflection*" would receive full credit. Answers must be in full, clear sentences. Points will be deducted for unclear or incomplete responses and improper grammar.

When you have completed the short-answer questions, you will hand it in to the proctor, and then will be given eight (8) problems from which you must choose five (5) to solve. You will be given an exam book to enter your work. While you can use scrap paper for your own use, only solutions written in the exam book will be graded.

During this problem portion of the test, references to notes, computers, calculators, and books are allowed. Most of the questions are in a problem format and all work must be shown, even if computers or calculators are used to assist in calculations. In addition, sources and references for formulas and approaches must also be shown and cited.

Both short-answer and problem portions must be completed in the four hours. After a one-hour lunch break, this question/problem format is repeated during the four-hour afternoon session of the exam. Note that there is no time limit on the short-answer question portion of the exam. Whenever the examinee finishes the short-answer question portion, they will be given the problem portion of the exam. A summary of the exam day is as follows:

7:45 am	Arrive at the exam room. Find a workspace. Set up your workspace and plug in computational aids, if necessary.
7:50 am	The proctor will take attendance and read the exam instructions
8:00 am	The closed–book question portion of the exam will begin. Reference books may be placed on the workspace, but not opened. Computers and computational aids must be turned off. Ten questions are completed.
-	Hand in the question portion to the proctor when completed. You will be given the open-book problems. Answer 5 of 8 problems. Computational aids may be powered up and references used.
12:00 pm	Pencils down. The exam and solutions are handed in to the proctor.
12:00 to 12:55	Lunch on your own
12:55	Attendance will be taken again.
1:00	The closed–book question portion of the exam will begin. Reference books may be placed on the workspace, but not opened. Computers and computational aids must be turned off. Ten questions are completed.
-	Hand in the question portion to the proctor when completed. You will be given the open-book problems. Answer 5 of 8 problems. Computational aids may be powered up and references used.
5:00	Pencils down. Hand in the exam and solutions to the proctor.

The twenty (20) short-answer questions are worth 30% of the total exam score. The ten (10) problems are worth 70% of the total exam score. Sample questions and problems are provided at the end of this document for both the short-answer questions and problem portions of the exam. Both question and problem portion of the exam are graded on a partial-credit basis.

HINTS FOR SUCCESS

Knowledge of noise control engineering prior to taking the exam and time management while taking the exam are the two key issues to successful completion of the Board Certification exam. Knowledge in noise control engineering required to pass this exam is the result of both education and practical work experience. The INCE Board Certification application process helps insure that only candidates with suitable backgrounds are permitted to take this exam.

Preparation for the exam should involve a significant period of study. This exam is at least as difficult as those used to obtain professional engineering (PE) licenses. A list of exam topics is given on the following pages along with a bibliography. The candidate should review the exam topics and be familiar with the technical aspects of each (or at least most) of these areas. Since you are able to select ten (10) problems out of sixteen (16), you may be able to eliminate certain specific topics.

The candidate should review the portions of the textbooks listed in the bibliography that cover the exam topics. A key skill is being able to find the right equation (or equations) and apply the equation to solve the given problem in a minimum amount of time. Given that the textbooks listed in the bibliography have overlapping coverage of noise control topics, the candidate should determine before the test which text the candidate will use for which type of problem. However, it is certainly not required to bring and use all texts listed in bibliography. However, keep in mind that many of the problems have been created around these references.

On the other hand, the solutions to other problems may not be found in these, but in other references. Therefore, while you should certainly bring in the recommended references, you should also bring other references for which you feel comfortable. As one example, these references do not have equations used in engineering economics, so you should bring relevant tables or charts, such as those found in Professional Engineering exam study guides. While there is no limit to the number of books and reference materials allowed in the exam, too many reference texts can become distracting or confusing.

We recommend that you do not use class notes or texts that are not widely available. If you use an uncommon equation or method, and you reference a source that the grader cannot locate, you may not be given credit for that piece of the problem.

Reviewing the sample problems are a good start in preparation. However, these are *not* intended to be the sole means of self-study. They are intended to show examples of the depth and nature of the exam material. No other exam questions and problems are available or released by INCE. Several good acoustics textbooks are available that have problem sets with solutions that you can practice with.

Time management during the exam period itself is another factor that contributes to success. The candidates should take as short amount of time as possible to complete the short-answer questions. Two minutes per question should be adequate and thus this section should be completed in no more than a half hour. This leaves the candidates about 3 ½ hours for the problems in the open-book part of the exam. With five problems, this gives the candidate about 45 minutes per problem. The candidates are strongly encouraged to watch time spent the question part of the exam and each problem and use time to complete as many problems as possible. Partial credit will be given, but leaving a question or problem blank will result in no credit.

Since you choose five (5) of eight (8) problems to solve, we recommend reviewing each problem prior to starting the section, so that you can choose the ones that are easiest for you to complete. Read the problems carefully. Some problems that may look straightforward are not. Since the grading is partial credit, we recommend solving the easiest first, to get the most points, and the hardest last.

Many candidates get stuck on one part of one problem and then run out of time. Remember that this is a partial-credit exam, so if you are stuck, consider moving onto another part of the problem or another problems and coming back later.

Most problems are multi-part, where the answer to one part is dependent on the answer to another part. Since this exam is graded with partial credit, even if you get the first part wrong, you can still get full credit for the subsequent dependent parts of the problem.

Laptop computers are allowed in the open-book problem portion of the exam. Some problems require repetitive calculations which computer spreadsheets are very good for. If you bring a computer, you should also bring an extension cord and power strip since outlets may be in short supply in the exam room. Note that printers are not allowed and even if computers are used, <u>all work must be shown</u> in the exam book provided by INCE.

Time management is one of the keys to success. While the proctor may call out the time at specified intervals, you should bring a watch or small clock to keep track of time.

Snacks and drinks are allowed in the exam. Please do not disturb others when unwrapping food items.

HOW TESTS ARE GRADED; PASSING/FAILING

After completion of the exam, the questions and problem exam booklets are copied and sent to multiple graders (usually three people from the Board Certification Exam Subcommittee). Each grader is given an answer key, but it is up to the grader to develop their own method of scoring the candidates based on their best judgment. Typically, each grader grades all candidate exams.

The grades are compiled for each candidate. Any significant discrepancies in scores may require re-grading, as necessary. It takes about four months to grade the exams.

The passing grade is 70%, where 30% of the grade is from the short-answer portion of the exam and 70% is from the problem portion. While Board Certification can only be obtained after INCE Board of Directors approval, you may be notified of your exam pass/fail status prior to the next Board of Directors meeting.

The names of those taking the exam are confidential and known only to the Board Certification Committee, the graders, and authorized IBO staff. Only the names of those passing the exam are sent to the Board of Directors for Board Certification final approval.

If you fail the exam, you are permitted to sit for up to two (2) of the next administrations of the examination without formally re-applying and without payment of an additional application fee. While you do not have to reapply, you need to notify the IBO of your intent to retake the exam by the normal application deadline. After the third attempt to achieve a satisfactory grade on the examination, a candidate shall re-submit a new application (including payment of the application fee in effect at that time) prior to subsequent attempts to take the examination. References originally submitted with the initial application may be used for subsequent applications if the reference has been submitted within the previous five (5) years.

The application dossier for each applicant who achieves a satisfactory grade on the Professional Examination shall be reviewed by the Board Certification Committee for determination by majority vote of whether to recommend to the INCE Board of Directors that the applicant be granted the status of INCE Board Certification.

Please email the INCE Business Office if you have any additional questions on the exam.

SUGGESTED REFERENCE BOOKS FOR THE EXAM

Reference books are allowed in the open-book problem portion of the exam. Books can be flagged with post-its or similar organizational aids. Three-ring notebooks, personal notes, and class notes are also allowed, but not encouraged, since graders will not have access to these if an unfamiliar method or equation is used.

We recommend bringing the "Recommended References" to the exam. Other texts may be uses as well. Some of the better ones are noted below under "additional references." Some of these additional references are cited because the have problems sets which are useful for studying.

RECOMMENDED REFERENCES

1. Beranek, Leo, *Noise and Vibration Control*, Institute of Noise Control Engineering, Washington, DC, 1988 (revised edition).
2. Harris, Cyril M., *Handbook of Acoustical Measurements and Noise Control*, McGraw Hill, New York, 3rd Edition 1991 (and American Institute of Physics, 1998)
3. Harris, Cyril M., *Shock & Vibration Handbook*, McGraw Hill, New York, 1988.
4. Kinsler, Lawrence E., Austin R. Frey, Alan B. Coppens and James V. Sanders, *Fundamentals of Acoustics*, John Wiley & Sons, New York, 2000.

ADDITIONAL REFERENCES

1. Ver, Istvan and Beranek, Leo and, *Noise and Vibration Control Engineering: Principles and Applications*, John Wiley and Sons, Inc., New York, 2006.
2. Bies, David and Hansen, Colin, *Engineering Noise Control: Theory and Practice*, E&FN Spon, New York, 1996 (second edition).
3. Cremer, Ing, M. Heckl, and Eric Ungar; *Structure Borne Sound: Structural Vibrations and Sound Radiation at Audio Frequencies,* Springer-Verlag, Germany 1988.
4. Crocker, Malcolm*, Handbook of Noise and Vibration Control*, John Wiley & Sons, Inc. Hoboken, New York, 2007.
5. Grant, Ireson, Leavenworth; *Principals of Engineering Economy,* Roland Press, New York, 1990.
6. Hansen, Colin, *Noise Control from Concept to Applicatio*n, Taylor & Francis, New York, 2005.
7. Fahy, Frank *Sound and Structural Vibration: Radiation, Transmission, and Response,* Academic Press, New York, 1985.
8. Rossing, Thomas, *Handbook of Acoustics*, Springer, New York, 2006.

9. Reynolds, Douglas M. and Jeffrey M. Bledsoe, *Algorithms for HVAC Acoustics*, American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) 1991.

EXAM TOPICS

The exam is divided up into ten categories and there are usually at least one question from each offered in the problem portion of the exam. The topics are shown in the table below along with the percentage of questions on each topic on a typical exam.

Categories	Approximate number of questions on each exam
Engineering Economics	1
Instrumentation	1
Vibration	3
Noise – General	2
Room Acoustics	1
Noise Control	2
HVAC	1
Loudness	1
Air Moving Devices	1
Transportation Noise	1
Noise Transmission	2

There are a variety of topics within these categories. Some subtopics from past exams include:

Equipment financing	Direct & reverberant fields	Traffic noise
Spectrum analyzer filters	Loudness	Levels
Vibration transmission	Dipoles and monopoles	Radiation efficiency
Damping	Directivity	Accelerometer measurements
Vibration mounts	Hearing	Wave speeds
Destructive interference	Hearing conservation	Sound absorption
Impedance tubes	Fan laws	Gaps and leaks
Sound intensity measurements	Passive noise cancellation	Imbalance and vibration
Highway sound barriers	Panel resonance	Impedance
Outdoor sound propagation	Room modes	Transfer functions
Sound through ducts	Common partitions	TL through beams & plates
Engine noise	STC and IIC	Critical frequency
Mufflers	Reverberation Time	Coincidence dip
Statistical Energy Analysis	Sound power measurements	Noise dose
Sound masking	Transmission loss	Enclosures
Line sources	Insertion loss	Underwater sound
Industrial noise control	Aircraft noise	

INCE PROFESSIONAL EXAMINATION INSTRUCTIONS

General

1. Write your last name at the top of this sheet. Place it into the exam packet at the conclusion of the exam.
2. Turn off your cell phone. No internet access is allowed. Turn of wireless radios.
3. You have four hours to complete the AM and four hours to complete the PM portion of the examination.
4. Your writing must be legible and darkly written in order that legible copies can be made for distribution to graders.
5. If you have questions, you may ask the proctor for assistance. Proctors may not be INCE Board Certified; however, the proctor can arrange for an INCE Board Certified member in the area to come to the room to answer any questions you may have. If a question is asked, the Board Certified Member will restate the question to all those taking the exam and state the answer. If this person is not able to answer the question, you must state your question in the exam booklet and suggest your assumed answer, and continue the exam on the basis of your assumption.
6. When you are finished, place all exam materials, (i.e., the exams and the exam booklets, and any scrap paper used) into the envelope provided. Seal the envelope, make sure your name and date appear on the outside of the envelope, and return it to the exam proctor. Do not save and otherwise delete any work done on a electronic devices

Closed-book Questions Section

7. Write your name, date, and exam location on the cover of the short answer exam booklet.
8. You will start on the short-answer exam first. Answer questions only in the space provided. Do not use formulas in your answers.
9. This portion of the exam is closed-book. No references or computational aids are allowed. Please turn off computation aids and close all books.
10. Answer <u>all</u> questions in this portion of the exam.
11. Write clearly and <u>legibly</u> in complete sentences.
12. After completing the questions, hand them to the proctor, and you will then be given eight (8) problems.

Open-book Problems Section

13. Write your name, date, and exam location (city, state) on the cover of your exam booklet.

14. The problem portion of the exam is an open-book. Any reference materials and computational aids are for your personal use only. Allowable computational aids include calculators, computers, software programs, handbooks, data tables, and nomographs. Electronic equipment used must not interfere with others taking the exam.
15. Work five (5), and not more, of the eight (8) exam problems in the AM and PM portions of the exam. All problems are of equal scoring weight. If more than five are answered, indicate those that are to be counted in your score. Cross-out problems you wish not to be included in the five problems to be scored. If more than five problems are completed, and those beyond the five are not crossed-out or otherwise indicated to be not scored, then the first five problems will be scored.
16. Write only in the exam booklets. Start the solution to each problem on a clean page in your exam booklet.
17. As part of each solution, cite the references you have used.
18. Mark your answers clearly with an underline or box.
19. Sufficient paper has been provided in exam booklets so that scrap paper should not be needed, but if scrap paper is used it must be placed into the exam envelope and is to be discarded by INCE. Scoring will not consider any information included on scrap paper. Only information entered into the exam booklets will be considered. You are honor-bound to discard any data or other information taken from the exam questions or their solutions and used in your personal computer.
20. A printer will not be provided for your use during the exam. If you should bring a printing device with you and choose to use it, it must not interfere with others taking the exam, and any materials printed are considered scrap paper and must be handled as described.
21. You are not permitted to exchange any reference materials or computational aids with others during the examination. Using computational aids does not preclude showing all problem solving steps. You must show all work as if computational aids were not used, unless such aids are provided in the problem (such as data tables).
22. On the cover of your exam booklet, write the numbers of the five problems you have worked in the order that they appear in the booklet. The number for each problem appears at the bottom left corner of each problem page. These numbers are unique to the problem and are not necessarily sequential.

- **READ THE PROBLEMS CAREFULLY.**
- **STATE ASSUMPTIONS MADE.**
- **USE METRIC UNITS THROUGHOUT.**
- **MARK THE FIVE (5) PROBLEMS THAT ARE TO BE GRADED AND COUNTED IN YOUR SCORE.**
- **CROSS-OUT PAGES YOU WISH NOT TO BE CONSIDERED.**

SAMPLE SHORT-ANSWER QUESTIONS

Answer the following question is a few sentences. Do not use equations, although descriptions of relationships and formulas are acceptable. Clarity and comprehensiveness will be factored into the grading of your answers. Use only the space provided. [Answers are given on the following pages.]

1) What is the A-weighting network, what is it based on, and what is it used for?

2) Inside a duct, what is the cutoff frequency?

3) What is the equivalent-continuous level?

4) What is a phase speed?

5) What is a resilient mount and name two types of mounts in common use.

6) What is Room Criteria (RC)?

7) What is an acoustic transducer and give an example?

8) What is the principle underlying active noise control? What is good application of it and what are limitations.

9) What is designation "Lp"? What are typical units of measure and reference units?

10) What are bearing frequencies in proportion to (no equations necessary)?

SOLUTIONS TO *SAMPLE* CLOSED-BOOK SHORT-ANSWER QUESTIONS

1) What is the A-weighting network, what is it based on, and what is it used for?

An A-weighting network is a frequency filter that simulates the subjective response of loudness to pure tones as a function of frequency, with a sound pressure level at 1000 Hz of 40 dB re 20µPa. It is used to measure overall sound levels and in specification of maximum noise exposure levels. It is used frequently in environmental noise measurements and standards. It is not appropriate for use with high-energy sounds.

2) Inside a duct, what is the cutoff frequency?

The cutoff frequency is the frequency below which sound will not propagate inside the duct for a given cross-sectional mode.

3). What is the equivalent-continuous level?

The equivalent-continuous level of a sound is the level of the time-average of the squared acoustic pressure. Referred to as Leq. For any time varying sound, the Leq is the constant level of sound for a specific period of time which has the same acoustic energy as the varying sound.

4) What is a phase speed?

The phase speed is the speed at which a point on a wave at a constant phase travels. The phase speed is the same as the sound speed for acoustic wave.

5) What is a resilient mount and name two types of mounts in common use.

A resilient mount is used to attach a piece of equipment or machinery to its foundation which are designed to reduce the transmission of the vibration from the vibrating device to the foundation, or from the vibration foundation to the device. The two types in common use are rubber and metal spring.

6) What is Room Criteria (RC)?

The Room Criteria is a method of rating the background noise in a room generated by the HVAC system in the room.

7) What is an acoustic transducer and give an example?

A transducer is a device that converts a physical quantity into a measurable electric voltage or charge. Microphones, hydrophones, geophones (velocity) and accelerometers are examples of transducers.

8) What is the principle underlying active noise control? What is good application of it and what are limitations.

The superposition of the noise to be control and noise generated by the active control system such that the two are out of phase. That is, the active control system generates noise that is 180 degree out of phase with the original noise at the location of interest, so that the noise generated by the active noise control system 'cancels' the original noise. Good applications are noise sources that have significant single frequency or tonal characteristics. For example, HVAC systems, engine exhaust systems. Active noise control is not good for broadband noise reduction, it is best for 1-D applications such as ducts or pipes and not as good for 3-D environments.

9) What is designation "Lp"? What are typical units of measure and reference units?

Lp (or L sub p) is the shorthand designation for "Level Pressure" or Sound Pressure Level (SPL). The units of measure are pressure, but reported in decibels. The reference unit for airborne measurement is 20 micro-Pascals and the reference unit for underwater pressure is 1 micro-Pascal.

10) What are bearing frequencies proportion to (no equations necessary)?

Bearing frequencies are proportional to the bearing geometry such as bearing inner diameter, outer diameter, ball diameter. Bearing frequencies are also always proportional to the bearing contact angle and the shaft speed the bearing is supporting.

SAMPLE PROBLEMS

This is the open book portion of the exam.

As a reminder, you are given four hours to complete the previous short-answer questions and five of eight problems.

SAMPLE PROBLEM 1 **TOPIC: ECONOMICS**

An engineering firm buys a new dual channel, real-time analyzer for $100,000. Careful handling of depreciation can yield substantial tax savings. Assume that the useful life of this piece of equipment is 5 years. Construct the depreciation over the life of the equipment for the following depreciation models.

(a) Straight-line depreciations
(b) 200% declining balance depreciation
(c) Sum-of-the-years-digits depreciation

Which method yields the greatest cumulative depreciation at the end of the second and fourth year?

SAMPLE PROBLEM 2 **TOPIC: NOISE GENERAL**

A sound intensity probe will be used to measure the radiated power from an engine. Measurements are performed on a semi-cylindrical surface, radius 0.5 meter and length 1.5 meters. The spacing of the measurements around the cylindrical axis are spaced 20 degrees radially starting from 10 degrees from the horizontal, and 0.15 meter along the cylindrical axis starting at 0.075 m from the edge. Only one measurement is performed to represent sound radiated from each end of the cylindrical surface. The microphone of the intensity probe are separated by a distance of 5 cm and the phase accuracy of the microphone pair is 1.5 degrees. It is desired to have not more than 2.5 dB error in the measurement of intensity. Calculate:

(a) The low frequency cut-off of the intensity probe.
(b) The upper frequency cut-off.
(c) The total sound power level radiated by the engine if the average sound intensity measured at the two ends is 0.1 watts/m^2 and the average intensity measured on the semi-cylindrical surface is 0.025 watts/m^2. Assume that the semi-cylindrical surface is bounded by a hard surface along the flat ground surface.

SAMPLE PROBLEM 3 **TOPIC: LOUDNESS**

The octave band sound pressure levels of three engines (X, Y and Z). Each engine is composed of the engine block and a cooling fan. The sound is steady and has no significant discrete frequency components.

Frequency - Hz		63	125	250	500	1k	2k	4k	8k
Octave band Sound pressure in dB re 20µPa	Engine X	56	58	59	60	66	68	65	60
	Engine Y	60	60	60	60	60	60	60	60
	Engine Z	70	66	62	60	59	55	51	48

(a) Calculate the loudness in sones for each engine. Which engine would be expected to be judged to be the loudest?
(b) The octave band noise levels for the fan in Engine X are shown below. Without the Engine X fan noise, is the loudness of Engine X lower than Engine Y or Z? Show your work.

Frequency - Hz		63	125	250	500	1k	2k	4k	8k
Octave band Sound pressure in dB re 20µPa	Fan in Engine X	40	53	58	57	59	64	60	55

SAMPLE PROBLEM 4 **TOPIC: VIBRATION**

An upper floor slab in a factory building measures 8 m x 8 m. Its mass, with no equipment installed on it, is 20,000 kg. Placement of a piece of equipment of 2,500 kg mass near the center of the slab deflects the slab center by 0.5 mm.

(a) What is the approximate fundamental resonant frequency of the slab without the equipment in place?

(b) When the equipment was rigidly attached to the center of the slab, it was found that it vibrated vertically due to slight imbalance. If the equipment rotates at 900 rpm and the amplitude of the excitation force is 200 N, what is the displacement amplitude of the slab?

SAMPLE PROBLEM 5 **TOPIC: VIBRATION**

A flat steel panel, 1 mm thick, on a domestic appliance resonates unacceptably under normal operating conditions. Tests on the panel show that its loss factor is 0.004. An unconstrained layer of damping treatment is to be applied uniformly on one surface to alleviate the problem and to reduce the acceleration amplitude by 95%. Given the following material properties, determine approximately the thickness of the damping material which must be applied.

$E_{steel} = 21.0 \times 10^{10}$ N/m^2;
$E_{damping} = 4 \times 10^{9}$ N/m^2;
$\eta_{damping} = 0.6$;
Density of steel = 8.0*Density of damping material.

Assume that the application of the damping treatment does not move the bending neutral axis from the mid-plane of the steel plate. Assume also that the response of the untreated and treated plates will be dominated by the fundamental resonance and the exciting broadband force remains the same.

SAMPLE PROBLEM 6 **TOPIC: NOISE CONTROL**

A 74.6 kW motor operating at 3,600 RPM produces excessive noise levels in the nearby community. The noise from the motor is dominated by a 500 Hz tone. The sound power Lw of the motor for the 500 Hz octave band is give by:

$$Lw = 12 + 10\log(\text{Power in kW}) + 20\log(\text{Speed in RPM})$$

The sound pressure level in the community should not exceed 50 dBA. Consider only hemispherical radiation and barrier effects. Assume a 1 meter source height, 1.5 meter receiver height, and 25 meter distance along the ground from source to receiver.

a) If a brick wall were placed 5 meters from the motor, what height would be necessary to achieve the desired sound pressure levels. Assume the wall is much longer than the motor.

b) How far from the motor would a 2.0 meter tall barrier have to be located to achieve the desired sound pressure level?

SAMPLE PROBLEM 7 **TOPIC: NOISE CONTROL**

A 2m X 2m X 2m enclosure is constructed around a small compressor. The enclosure is made of a lightweight metal with a transmission loss of 26 dB at 500 Hz. The average absorption coefficient in the enclosure is 0.3 in the 500 Hz octave frequency band.

The compressor generates a sound power level of 105 dB in the 500 Hz octave band.

a) Calculate the A-weighted sound power level radiated by the exterior of the enclosure. Assume the interior of the enclosure is diffuse.
b) Calculate the maximum available open area for ventilation in the enclosure that will result in a sound level of 55 dBA for the 500 Hz octave band at a distance of 25 meters. Assume hemispherical radiation and ignore ground effects.
c) If the ventilation openings in the enclosure must be at least 0.5 m^2 in area, what is the minimum acceptable average absorption coefficient for inside of the enclosure that would result in a sound level of 55 dBA at a distance of 25 meters?

SAMPLE PROBLEM 8 **TOPIC: NOISE TRANSMISSION**

A 4 meter by 4 meter office is located next to a 6 meter by 8 meter mechanical equipment room. Between the two rooms is a wall with a very high transmission loss (TL) (assume > 60 dB). In the wall between the two rooms is a door, area 2 m^2. There are gaps all around the door. The only absorption in the office is provided by the acoustical tile ceiling. The following 1000 Hz octave frequency band sound pressure levels are measured in the rooms.

Location	**Sound Pressure Level 1000 Hz Octave Band (dB)**	**Condition**
Office	69	Door open
Mechanical Equipment Room	77	Door open
Office	54	Door closed
Mechanical Equipment Room	80	Door closed
Office	47	Door closed and gaps temporarily sealed with high TL treatment

Assume acoustical fields are diffuse in both rooms. All the noise is from a sound source in the mechanical equipment room. There are no wave effects in the gaps around the door.

Determine:

(a) The absorption coefficient of the ceiling in the office.

(b) The TL of the door.

(c) The total area of the gaps around the door.

(d) The effect of adding a ceiling treatment with a 1000 Hz octave band absorption coefficient of 0.90 to the entire ceiling of the office, assuming that the door is closed.

SAMPLE PROBLEM 9 **TOPIC: TRANSPORTATION**

A house in a residential neighborhood 2000 meters (2Km) from a medium-sized airport is subjected to 40 aircraft operations (20 takeoffs and 20 landings) each day. Ten percent of these operations occur at night. The airport has only one runway (9-27) which points in the direction of the house. The prevailing wind blows in a westerly direction from the neighborhood towards the airport.

Assume that:

(e) the altitude of a typical aircraft 2 Km from the airport is 400 meters on takeoff and 150 meters on landing;

(f) the aircraft speed is 300 km/hr for either landing or takeoff;

(g) the directivity pattern of the aircraft may be represented by a dipole with maximum radiation at 90 degrees to the aircraft's axis (see NOTE below);

(h) the A-weighted sound pressure level of the aircraft is 105 dBA re $20\mu Pa$ at 150 meters during takeoff and 105 dBA at 50 meters during landing.

Rounding your answers to the nearest dB.

(i) What is the sound exposure level experienced at the house during a typical take-off?

(ii) What is the LDN sound level in the neighborhood from the aircraft operations, assuming that the typical aircraft is representative of all aircraft?

(iii) What is your assessment of the noise level in the neighborhood of the house?

NOTE: The effective duration for a moving 90 degree dipole equals $\pi R_0 / 2V$, where R_0 is the shortest distance to aircraft and V is the velocity of aircraft.

SAMPLE PROBLEM 10 TOPIC: ROOM ACOUSTICS

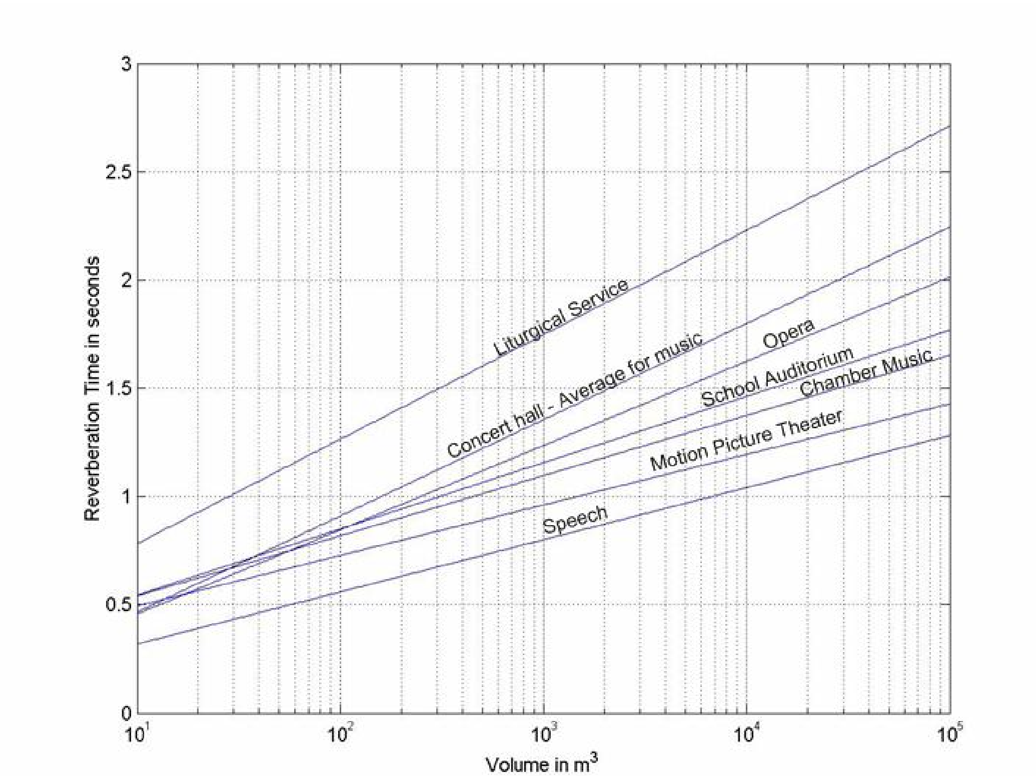
You are the consultant for the acoustic design of an auditorium. For practical reasons, two loudspeakers need to be placed in opposite upper corners in the front of the 15 meters wide auditorium. One important acoustic specification is that the sound should appear everywhere to be coming from the center of the stage, with no perceivable direct contribution from the loudspeakers.
The minimum distance of the audience from any of the two speakers is 4 meters. After the audience layout is established, you proceed in preliminary calculations to select the proper wall and ceiling materials.

(a) Assuming the speakers behave like ideal, monopole sound sources when operated in free field, what is the directivity of each source, Q_θ when operated in a corner? (assume rigid walls).

(b) Assuming the room volume is $1500\ m^3$, and the total surface area of the walls, floor, and ceiling is $950\ m^2$, if the mean absorption coefficient is 0.65, what is the maximum distance from the speakers within which the direct field is at least 3 dB higher than the reverberant field.

(c) Evaluate the resulting reverberation time. Will the room be satisfactory for speech production (see graph enclosed)?

(d) In those areas where the reverberant contribution is significant, what solution is possible to improve speech intelligibility.



SOLUTIONS TO SAMPLE PROBLEMS

SOLUTION SAMPLE PROBLEM #1:

(a) – Straight line depreciation (SL)
Amount of depreciation = $100,000
5 years at a depreciation rate of 100%/5 = 20%/year
yearly depreciation - $20,000

Year	Depreciation	Dep. Value	Residual Value
0	-	-	$100,000
1	$20,000	$20,000	80,000
2	20,000	40,000	60,000
3	20,000	60,000	40,000
4	20,000	80,000	20,000
5	20,000	100,000	0

(b) – 200% declining balance depreciation (DDB)
double declining percentage is 2*20% = 40%
depreciation = 40% of residual value

Year	Depreciation	Dep. Value	Residual Value
0	-	-	$100,000
1	$100,000*0.40=40,000	$40,000	60,000
2	60,000*0.40=24,000	64,000	36,000
3	36,000*0.40=14,400	78,400	21,600
4	21,600*0.40=8,640	87,040	12,960
5	21,960*0.40=5,184	92,224	7,776

(c) – Sum of years digits (SYD)
5 years useful life → sum of year digits = 5+4+3+2+1 = 15

Year	Depreciation	Dep. Value	Residual Value
0	-	-	$100,000
1	$100,000*(5/15)=33,333	$33,333	66,667
2	100,000*(4/15)=26,667	60,000	40,000
3	100,000*(3/15)=20,000	80,000	20,000
4	100,000*(2/15)=13,333	93,333	6,667
5	100,000*(1/15)=6,667	100,000	0

(d) -

Depreciation Scheme	End of 2nd Year	End of 4th Year
SL	$40,000	$80,000
DDB	64,000	87,040
SYD	60,000	93,333

The DDB gives the highest after 2 years while the SYD gives the highest after 4 years.

SOLUTION SAMPLE PROBLEM #2:

20 degree spacing – 9 measurements around the circumference
0.15 m along the axis – 10 measurements axially

(a) Low frequency cut-off is controlled by phase accuracy

$L_\varepsilon = 10\log\left(1 \pm \frac{\Delta\alpha}{\Delta\phi}\right)$, where $\Delta\alpha$ is the phase accuracy of the probe and $\Delta\phi$ is the maximum acoustic phase difference, i.e. for acoustic incidence in the direction along the probe axis

$$\Delta\phi = \frac{\Delta d}{\lambda}360 \text{ degrees} = \Delta d\frac{f}{c}360 \text{ degrees}$$

$$\pm 2.5 = 10\log\left(1 \pm \frac{1.5 * 343}{0.05 f 360}\right)$$

$$10^{\pm 0.25} = 1 \pm \frac{1.5 * 343}{18 f}$$

$$1.77 = 1 + \frac{1.5 \times 343}{18 f} \text{ or } 0.56 = 1 - \frac{1.5 \times 343}{18 f}$$

f = 36.8 Hz or f = 64.4 Hz

Hence the low frequency cut-off is 64.4 Hz

(b) High frequency error is caused by finite difference approximation, thus this error is given by

$$L_\varepsilon = 10\log\left(\frac{\sin(k\Delta r)}{k\Delta r}\right)$$

$$\Delta r = 0.05m,\ k = 2\pi/\lambda = 2\pi f/c, \text{ c = 343 m/s}$$

$$10^{\pm 0.25} = \frac{\sin\left(\frac{2\pi f}{343}0.05\right)}{\frac{2\pi f}{343}0.05}$$

$$\sin\left(\frac{2\pi f}{343}0.05\right) = \frac{(2\pi f)(0.05)}{343}10^{\pm 0.25}$$

f = 1910 Hz for $10^{-0.25}$; no solution for $10^{+0.25}$

Hence, upper frequency limit is 1910 Hz.

(c) Power - $P = \sum_i I_i A_i = I_{rad} 2\left[\frac{1}{2}\pi r^2\right] + I_{cly}\frac{2\pi r l}{2}$

$$P = 0.1\frac{watts}{m^2} * 2\frac{1}{2}\pi 0.5^2 + 0.025\frac{watts}{m^2} * \frac{\pi(0.5)(2)}{2} * 1.5 = 0.137 \text{ watts}$$

Sound Power Level - $L_W = 20\log\left(\frac{P}{10^{-12}\,watts}\right) = 111$ dB

SOLUTION SAMPLE PROBLEM #3:

(a) Loudness = $I_{max}+K(\Sigma I_i-I_{max})$, where I_i are the loudness indices and K is the bandwidth factor of 0.3 – obtained from
Fig. 17.7 in Harris – Handbook of Acoustic Measurement & Noise Control.

Engine X

Frequency – Hz	Level – dB	Loudness Index - I_i
63	56	1.0
125	58	2.0
250	59	3.0
500	60	4.0
1000	66	6.5
2000	68	10.0
4000	65	8.0
80000	60	8.0

$$\sum_i I_i = 42.5;\ I_{max} = 10.0$$

Loudness = 10.0+0.3(42.5-10.0) = 19.8 sones

Engine Y

Frequency – Hz	Level – dB	Loudness index - I_i
63	60	2.0
125	60	2.5
250	60	3.2
500	60	4.0
1000	60	5.0
2000	60	5.5
4000	60	6.5
8000	60	8.0

$$\sum_i I_i = 36.7;\ I_{max} = 8.0$$

Loudness = 8.0+0.3(36.7-8.0) = 16.6 sones

Engine Z

Frequency – Hz	Level – dB	Loudness index - I_i
63	70	3.0
125	66	4.0
250	62	4.0
500	60	4.2
1000	59	4.5
2000	55	4.5
4000	51	4.0
8000	48	4.0

$$\sum_i I_i = 32.2;\ I_{\max} = 4.5$$

Loudness = 4.5+0.3(32.2-4.5) = 12.8 sones

The loudest is Engine X

(b) Remove fan noise from Engine X

$$L_{w/ofan} = 10\log\left(10^{L_{eng}/10} - 10^{L_{fan}/10}\right)$$

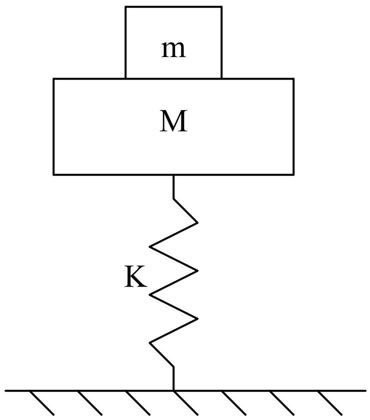
Freq – Hz	Overall Levels	Fan Noise Levels	Level without Fan	I_i
63	56	40	56	1.0
125	58	53	56	2.0
250	59	58	52	2.2
500	60	57	57	3.2
1000	66	59	65	6.2
2000	68	64	66	8.0
4000	65	60	63	8.2
8000	60	55	58	7.0

$$\sum_i I_i = 37.0;\ I_{\max} = 8.2$$

Loudness = 8.2+0.3(37.8-8.2) = 17.1

Without fan, Engine X is still louder than Engine Y and Engine Z.

SOLUTION SAMPLE PROBLEM #4:



Stiffness of floor – K - $\frac{2500 \times 9.81}{0.5 \times 10^{-3}}$ = 49.05x10^6 N/m

(a) Resonant frequency of bare floor

$$\omega_0 = \sqrt{\frac{49.05 \times 10^6}{20{,}000}} = 49.5 \text{ rad/sec}$$

$$f_0 = \frac{\omega_0}{2\pi} = 7.9 \text{ Hz}$$

(b) Ω = 900 rpm → $\frac{900}{60}$ = 15 Hz = 30π rad/sec

F = 200 N

$$(M + m)\ddot{x} + kx = F$$

$$x = \left| \frac{F}{K - \omega^2 (M + m)} \right| = \left| \frac{200}{49.05 \times 10^6 - (30\pi)^2 (22500)} \right| = 1.3 \times 10^{-6} \text{ m}$$

SOLUTION SAMPLE PROBLEM #5:

The base steel plate does not dissipate any significant energy. Hence from the definition of damping loss factor, if η_c is the damping loss factor for the treated plate, then

$$\eta_c = \frac{E_{diss}}{\omega E_{rotal}}.$$

Energy dissipated in the damping material = $\omega\eta_d$ *(max stored energy in the damping layer). Energy dissipated in the damping layer then is

$$\eta_c = \frac{\omega\eta_d E_d I_d}{\omega(E_d I_d + E_s I_s)},$$

layer, where I_d, I_s are the second moments of area about the combined neutral axis. To reduce the vibration by 95%,

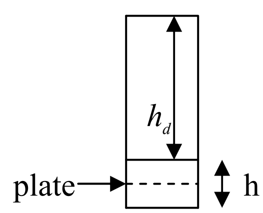
$$\frac{1/\eta_c}{1/\eta} = 0.05,$$

where $1/\eta$ represents the amplitude of the vibration at resonance, since the amplitude of vibration at resonance is proportional to $1/\eta$. Hence,

$$\eta_c = \frac{\eta}{0.05} = \frac{0.004}{0.05} = 0.08, \text{ and}$$

$$\frac{\eta_c}{\eta_d} = \frac{0.08}{0.6} = \frac{E_d I_d}{E_d I_d + E_s I_s}$$

$$I_d = \frac{h_d^3}{12} + h_d\left(\frac{h_d}{2} + \frac{h}{2}\right)^2 = \frac{h_d^3}{3} + \frac{h_d h^2}{4} + \frac{hh_d^2}{4}$$



With $I_s = \dfrac{h^3}{12}$,

$$\frac{0.08}{0.6} = \frac{4\left(\frac{h_d^3}{3} + \frac{h_d h^2}{4} + \frac{hh_d^2}{2}\right)}{4\left(\frac{h_d^3}{3} + \frac{h_d h^2}{4} + \frac{hh_d^2}{2}\right) + 210\frac{h^3}{12}} = 26\left(\frac{h_d^3}{3} + \frac{h_d h^2}{4} + \frac{hh_d^2}{2}\right) = 210\frac{h^3}{12}$$

$$\frac{210}{12} = \frac{26h_d^3}{3} + h_d\frac{26}{4} + \frac{26}{2}h_d^2$$

$$104h_d^3 + 156h_d^2 + 78h_d - 210 = 0$$

$$h_d = 0.79mm$$

SOLUTION TO SAMPLE PROBLEM 6

a) First, calculate the sound power level of the source.

Lw = 12 + 10log(74.6) + 20log(3600) = 101.8 dB

LwA at 500 Hz = 101.8 – 3.2 = 98.6 dBA

[**Comment**: *be careful to spot places in problems where A-weighting is necessary*]

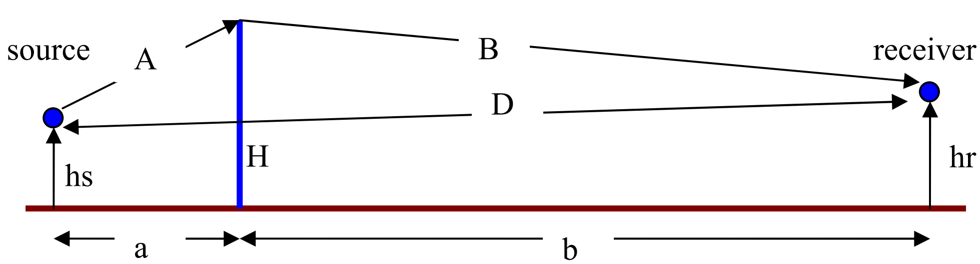
Without the barrier, assuming hemispherical spreading,

$Lp = Lw - 10\log(2\pi\, r^2) = 98.6 - 10\log(2\pi\, 25^2) = 62.7$ dBA

To achieve 50 dBA at the residence, the required excess reduction by barrier is 12.7 dBA (assuming 500 Hz is the only contributing octave band).

Next calculate the barrier height:

Assuming the density of the barrier wall is greater than 4 lb/square foot and the motor is a point source,



Attenuation provided by the barrier (ignoring ground absorption effects) = 10log(20N), where N is the Fresnel number (source: Crocker, Handbook of Acoustics, Chapt 28 eq 29)

$N = \frac{2}{\lambda}(A + B - D)$ (source, Crocker Handbook of Acoustics, Chapt 28, eq 28) [eq.1]

Where: λ is the wavelength,

$$A = \left[a^2 + (H - h_s)^2\right]^{0.5}$$
$$B = \left[b^2 + (H - h_r)^2\right]^{0.5}$$
$$D = \left[(a+b)^2 + (h_s - h_r)^2\right]^{0.5}$$

$$\lambda_{500} = \frac{c}{f} = \frac{344\ ^m\!/_s}{500Hz} = 0.688m$$

So,

Attenuation = 10log(20N)   (source, Crocker Handbook of Acoustics, Chapt 28, eq 29)

$$N = \frac{10^{A/10}}{20} = \frac{10^{12.7/10}}{20} = 0.93$$

Now insert this into the equation for the Fresnel number (eq 1, above),

$$0.93 = \frac{2}{0.688}\left\{\left[5^2 + (H-1)^2\right]^{0.5} + \left[20^2 + (H-1.5)^2\right]^{0.5} - \left[(5+20)^2 + (1-1.5)^2\right]^{0.5}\right\}$$

Solving for H is difficult as a closed form solution, so, using a computer spreadsheet and trial and error,

H	N	
2 meter	0.29	
3 meter	1.27	
2.7 meter	0.91	- close enough to N = 0.93

So the barrier height must be 2.7 meters.

b) If the barrier is 2 meters high instead of 2.7 meters, then

b = (25 - a) and

$$0.93 = \frac{2}{0.688}\left\{\left[a^2 + (2-1)^2\right]^{0.5} + \left[(25-a)^2 + (2-1.5)^2\right]^{0.5} - \left[(25)^2 + (1-1.5)^2\right]^{0.5}\right\}$$

$$0.93 = \frac{2}{0.688}\left\{\left[a^2 + 1\right]^{0.5} + \left[(25-a)^2 + (0.5)^2\right]^{0.5} - (5.0005)\right\}$$

Using a computer spreadsheet and trial and error:

a	N
5 m	0.29
10 m	0.15
2.5 m	0.56
1.4 m	0.93 ← Matches Fresnel Number for 12.7 dB reduction

A 2 meter high barrier must be 1.4 meters from the source for a 12.7 dB reduction.

SOLUTION TO SAMPLE PROBLEM 7

TL = 26 dB
Lw = 105 dB
LwA = 105 – 3.2 = 101.8 dBA

Part a

From Beranek, Noise & Vib. Control., eq 9.11. and assuming sound near the walls are dominated by the diffuse field inside the enclosure, interior sound pressure level inside the enclosure =

Lpi = Lw + 10log(4/R)   Source: from Beranek, Noise & Vib. Control., eq 9.11

S = the interior surface area = (2 X 2) X 6 = 24 m^2

V = the interior volume = 2 X 2 X 2 = 8 m^3

$$R = \frac{S\overline{\alpha}}{1-\overline{\alpha}} = \frac{(24)(0.3)}{1-0.3} = 10.3$$ Source: Beranek, Noise & Vib. Control., eq 8.16

Lp_i = 101.8 X 10log(4/10.3)
= 101.8 – 4.1
= 97.7 dBA

Next, calculate the sound power of the enclosure (Lw_e) assuming the interior sound level (Lp_i) radiates over the surface area of the enclosure (minus the transmission loss)

Lw_e = Lp_e + 10log(S) - TL   (from Harris, Handbook of Acoustics 3rd ed, 13.3)

- but S does not include the bottom of the enclosure in this case, so,

Lw_e = Lp_i + 10log(S-4) - TL   -
= 97.7 + 10log(24-4) - 26
= 97.7 + 13.0 -26

Lw_e = 84.7 dBA

Part b

$Lp_{receiver}$ = Lw_e – 10 log ($2\pi r^2$)   - Source, ibid where S = $2\pi r^2$
= 84.7 – 10 log ($2\pi\ 25^2$)
= 110.7 – 35.9
= 48.8

For an enclosure with an opening which is has an area Si of the wall area S, then the average transmission coefficient of the enclosure is

$$\bar{\tau} = \frac{1}{S}\sum_{i=1}^{n}\tau_i S_i$$

And

$$\tau = 10^{-\frac{TL}{10}} \text{ and } TL = 10\log\left(\frac{1}{\tau}\right)$$ (Beranek, Noise & Vibration Control, eq 11.19)

An opening has a $\tau = 1.0$ so

$$\bar{\tau} = \frac{1}{20}\left(\left(20 - S_{open}\right)\left(10^{-26/10}\right) + S_{open}\right)$$

Since Lp = 48.8 dBA at the receiver, the TL is 26, and the standard is 55 dBA, the transmission loss can be reduced by 6.2 dB and still meet the standard. The resulting effective TL_e = 26 - 6.2 = 19.8

$$TL_e = 19.8 = 10\log\frac{20}{10^{-26/10}\left(20 - S_{open}\right) + S_{open}}$$

$$S_{open} = \frac{20 - \left(10^{1.98}\right)(20)\left(10^{-2.6}\right)}{10^{1.98}\left(1 - 10^{-2.6}\right)}$$

S_{open} = 0.16 m^2

Part c

If the ventilation opening must be 0.5 m^2, then

$$TL_e = 10\log\frac{20}{10^{-26/10}(20 - 0.5) + 0.5}$$

TL_e = 15.6 dB

So the absorption in the enclosure must increase to compensate for this loss in TL.

The allowable TL was 19.8 dB and is now 15.6 dB, so the additional absorption must decrease to enclosure sound power by 4.2 dB.

The absorption reduction is represented by 10log(4/R) which at present equals -4.1 (see part a). So the goal is:

$$10\log\left(\frac{4}{R}\right) = -4.1 - (19.8 - 15.6) = -8.3$$

$$\left(\frac{4}{R}\right) = 10^{\frac{-8.3}{10}}$$

$$R = 27.0$$

$$R = \frac{S\overline{\alpha}}{1-\overline{\alpha}}$$

$$27 = \frac{24\overline{\alpha}}{1-\overline{\alpha}}$$

$$1-\overline{\alpha} = \frac{24}{27}\overline{\alpha}$$

$$\overline{\alpha} = \frac{1}{1+\frac{24}{27}}$$

$$\boxed{\overline{\alpha} = 0.53}$$

SOLUTION TO SAMPLE PROBLEM 8

$S_{office\ ceiling} = 4 \text{ X } 4 = 16 \text{ m}^2$
$S_{mechanical\ ceiling} = 6 \text{ X } 8 = 48 \text{ m}^2$
$S_{door} = 2 \text{ m}^2$

Part a

With the door open, NR = 77 – 69 = 8 dB. The open door has a TL of 0.0.

$$NR = TL + 10\log\frac{A}{S} \qquad \text{(eq 1)}$$

Source: From Beranek & Ver, "Noise & Vibration Control Engineering 1st ed" eq 9.78b

Where A is the absorption in the receiving room and S is the surface area

For the open door,

$$A = (S)10^{\frac{NR-TL}{10}}$$

$$A = (2)10^{0.8} = 12.6m^2$$

Since we now know A for the office, and the ceiling has the only absorptive surface, the average absorption coefficient of the ceiling is $A/S_{ceiling}$.

$$\boxed{\frac{A}{S} = \frac{12.6}{16} = 0.78}$$

(Note that some assumed open door absorption of 0 to 2 metric Sabines would also be acceptable)

Part b

With the door closed and gaps sealed,

NR = 80 – 47 = 33 dB

Using eq1 and rearranging,

$$TL = NR - 10\log\frac{A}{S} \qquad \text{eq 2}$$

$$TL = 33 - 10\log\frac{12.6}{2}$$

$$\boxed{TL_{door} = 25.0 \text{ dB}}$$

Part c

Lp with door closed but not sealed = 54 dB
Lp with door closed and sealed = 47 dB
Lp of sound coming through the gaps = $10\log\left(10^{54/10} - 10^{47/10}\right)$ = 53 dB (decibel subtraction)

NR for the gap only = 80 – 53 = 27 dB

Using eq 1

$$27 = TL + 10\log\frac{A}{S}$$

TL_{gap} = 0, so

$$S = \frac{A}{10^{27/10}}$$

With A = 12.6

$S_{gap\ under\ door} = 0.025\ m^2$

Part d

Source: Harris, "Handbook of Acoustical Measurements and Noise Control," 3rd edition eq 4.8

$$\Delta Lp = 10\log\frac{A_{before}}{A_{after}}$$

$$= 10\log\frac{(0.78)(16)}{(0.90)(16)} =$$

$$\boxed{\Delta L_p = 0.6 dB}$$

SOLUTION TO SAMPLE PROBLEM 9

Part i

If R_0 = 400m and V = 300 km/h then first calculate effective duration, J_T, according to the given formula.

$$\frac{\pi R_0}{2V} = T_T = \frac{\pi 400 \cdot 3600}{2 \cdot 300 \cdot 10^3}$$

$$= 7.54\text{s}$$

Lp = 105 @ 150 m
Convert to Lp at 400 m

$$Lp_{r1} = Lp_{r2} - 20\log\frac{r_1}{r_2} \qquad \textbf{(eq 1)}$$

$$Lp_{400m} = 105 - 20\log\frac{400}{150}$$

= 96 dBA at 400 m

SEL_{To} = Lp + 10log(T_T) (Source: Harris, Handbook of Acoustical Meas. 3rd Ed eq 11.18) **(eq 2)**
= 96.5 + 8.5
= 105 dBA

Part ii

SEL for Landing

$$T_L = \frac{\pi 150 \cdot 3600}{2 \cdot 300 \cdot 10^3}$$

= 2.8s

Lp = 105 dB at 50 meters (given)
Height of aircraft on landing = 150 meters (given)

Combining equation 1 and 2,

$$SEL_L = 105 - 20\log\left(\frac{150}{50}\right) + 10\log(T_L)$$

= 100 dBA

10% of the 20 takeoffs and 20 landings occur at night, so there are 18 takeoffs and 18 landings during the day and 2 takeoffs and 2 landings at night.

From Harris, eq 11.21,

$L_{DN} = 10\log\left\{\sum_{i=1}^{n} 10^{0.1L_{AE(i)}} + \sum_{j=1}^{n} 10^{10+0.1L_{AE(j)}}\right\}$ where L_{AE} is the SEL

$$LDN \quad = 10\log\frac{18\left(10^{105/10} + 10^{100/10}\right) + 2\left(10^{105+10/10} + 10^{100+10/10}\right)}{3600\cdot 24}$$

= 72.6 dBA

Part iii

72.6 dBA is considered as a very high LDN. Typically residential property is incompatible land use with this high LDN value.

SOLUTION TO SAMPLE PROBLEM 10

Basic equation is:

$$Lp = Lw + 10Log\left(\frac{4}{R} + \frac{Q}{4\pi r^2}\right)$$ Source: Beranek, Noise & Vib. Control., eq 9.11

Where Lp is sound pressure level, Lw is sound power level, R is the room constant, Q is directivity, and r is distance.

Part a

Assuming the speakers are placed near the auditorium ceiling, the Q factor would be 8 since the speakers are projecting their energy in 1/8 of the volume of a sphere with the speakers being assumed as monopoles. Speakers would however have their own Q factor which is not considered here.

Part b

V = 1500 m^3
S = 950 m^2
$\overline{\alpha} = 0.65$

$R = \frac{S\overline{\alpha}}{1-\overline{\alpha}}$ and represents the diffuse field component. (Source: ibid eq 9.9)

For the direct field to be 3 dB above the reverberant field,

$$\frac{\frac{Q}{4\pi r^2}}{\frac{4}{R}} = 2$$

$$\frac{8}{4\pi r^2} = \frac{2 \cdot 4}{950}\frac{(1-0.65)}{0.65}$$

r = 11.8 m where the direct field is more than 3 dB higher than the reverberant field

Part c

Reverberation Time

$$T_{60} = \frac{0.161V}{S\overline{\alpha}} = \frac{0.161 \cdot 1500}{950 \cdot 0.65}$$

Source: From Harris "Handbook of Acoustical Measurements and Noise Control, eq 4.5a

T_{60} = 0.39 seconds

For speech production, the reverberation time should be around 0.85 seconds (see provided chart). Thus, at 0.39 seconds, the reverberation time is below optimal. Speech will sound hollow and the hall will feel hard on the speaker.

<u>Part d</u>
The auditorium is not particularly well designed. The reverberation time is too low, that is, the absorption is too high, especially if uniformly distributed. If there are areas where the reverberation is high, reflecting surfaces should be identified and possibly treated. A disturbed sound system with localized speakers may also be considered. The consultant should recommend reducing absorption and placing most of the absorption material near the back wall of the auditorium. For still high reverberation areas, add absorption to back reflecting surfaces and possibly install localized sound amplification.