# ANALISA KEBISINGAN BANGUNAN: MODEL MENGGUNAKAN KAEDAH UNSUR TERHINGGA

## *BUILDING ACOUSTIC ANALYSIS: FINITE ELEMENT METHOD MODEL*

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## NOMENCLATURE

$\rho_o$ = mean fluid density

k = bulk modulus of fluid

P = acoustic pressure (=P(x, y, z, t))

t = time

[M] = structural mass matrix

[C] = structural damping matrix

[K] = structural stiffness matrix

$\{\ddot{u}\}$ = nodal acceleration vector

$\bar{P}$ = amplitude of the pressure

$j = \sqrt{-1}$

$\omega = 2\pi f$

c = speed of sound in fluid medium

{N} = element shape function for pressure

{N'} = element shape function for displacements

$\{P_e\}$ = nodal pressure vector

$\{u_e\} = \{u_{xe}\},\{u_{ye}\},\{u_{ze}\}$ = nodal displacement component vectors

f = frequency of oscillations of the pressure

Lsp = sound pressure level (output as SOUND PR. LEVEL)

log = logarithm to the base 10

$P_{ref}$ = reference pressure ($20 \times 10^{-6}$)

$P_{rms}$ = root mean square pressure ($P_{rms} = P / \sqrt{2}$)

# ABSTRACT

The acoustics characteristic is important subjects that need to be considered in designing room or educational building. Malaysia is currently in the midst of the largest campaign of improving the quality of educational building. With the increased emphasis on education, engineers and architects must seize the opportunity to end a long-standing Malaysian practice, which is not concerning with the building of lecture room with inferior acoustics. This invisible problem has far reaching implications for learning process such as students must either struggle to hear or else become distracted or stop playing attention. The main reason for these situations is lack of awareness of the acoustic problem and its solutions. To overcome this problem, engineers and architects must begin the design process with educational building acoustics in mind. For this project, ANSYS 7.0 was used to model the enclosed area in 2-D which represent a building/room. Loads applied in form of frequencies at the top right hand corner of the model and the frequencies are 40 Hz, 50 Hz, 60 Hz, 70 Hz and 80 Hz. The results presented in form of tables and contour plots. From the results, area which has maximum/minimum pressure level can be determined.

**ABSTRAK**

Ciri-ciri akustik merupakan perkara penting yang perlu dititikberatkan semasa merekabentuk sesuatu bilik atau bangunan pendidikan. Pada masa kini, Malaysia sedang melancarkan kempen bagi meningkatkan lagi kualiti bagi bangunan pendidikan. Para jurutera dan arkitek perlu mengambil kesempatan daripada dasar kerajaan Malaysia yang menekankan kepada pendidikan untuk menghapuskan amalan rakyat Malaysia yang memandang ringan terhadap masalah akustik di dalam bangunan pendidikan. Masalah ini telah memberikan kesan yang buruk terhadap proses pembelajaran seperti pelajar menghadapi kesukaran untuk mendengar, mudah bosan dan kurang penumpuan terhadap pelajaran. Punca utama situasi ini ialah disebabkan oleh kurangnya kesedaran terhadap masalah akustik dan juga penyelesaiannya. Bagi mengatasi masalah ini, para jurutera dan arkitek perlu mengambil kira ciri-ciri akustik pada bangunan pendidikan semasa proses merekabentuk dijalankan. Bagi projek ini, ANSYS 7.0 digunakan untuk memodel kawasan yang tertutup dalam keadaan 2-D yang mewakili sesebuah bangunan/bilik. Beban yang dikenakan adalah dalam bentuk frekuensi pada bucu atas sebelah kanan model dan nilai- nilai frekuensi yang dimasukkan ialah 40 Hz, 50 Hz, 60 Hz, 70 Hz dan 80 Hz. Keputusan yang diperolehi adalah dalam bentuk jadual dan peta kontor. Daripada keputusan yang diperolehi, kawasan di dalam model yang mempunyai paras tekanan maksima/minima dapat ditentukan.

# CHAPTER 1- INTRODUCTION

This project is based on last year project which was done by the last year student. Building acoustic is used to determine the acoustic mode of the building and the rooms near the building. Parameters affecting the relationship between the noise source such as air conditioning units and the overall level of the building acoustic will be modeled using FE. The main purpose of the building acoustic analysis project is to examine the noise sources which are emerged in a room and disturb a learning process. The noise level due to the sources is high and the study is to decrease the level.

The purpose of measuring sound level is to produce a noise contour map and to study the influence of background noise to the accuracy of measurement. The reverberation time measurement for lecture room in that building is also important.

Noise is a word used to describe sound conditions in certain instances. The most common operational definitions of noise are that it is unwanted sound [1]. Noise can affect the quality of sleep, our attitudes to neighbors and to the district we live in. A noise disturbance is defines as any sound that:

a) endangers or injures the safety or health of humans
b) annoys or disturbs a reasonable person of normal sensitivities
c) endangers or injures personal or real property.

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, acoustic, vibration, buckling behavior and many other phenomena. It can be used to analyze either small or large-scale deflection under loading or applied displacement. It can analyze elastic deformation, or "permanently bent out of shape" plastic deformation. The computer is required because of the astronomical number of calculations needed to analyze a large structure. The power and low cost of modern computers has made Finite Element Analysis available to many disciplines and companies. [2]

Finite Element Analysis makes it possible to evaluate a detailed and complex structure, in a computer, during the planning of the structure. The demonstration in the computer of the adequate strength of the structure and the possibility of improving the design during planning can justify the cost of this analysis work. FEA has also been known to increase the rating of structures that were significantly over designed and built many decades ago.

With Finite Element Analysis, the weight of a design can be minimized, and there can be a reduction in the number of prototypes built. Field testing will be used to establish loading on structures, which can be used to do future design improvements via Finite Element Analysis.

**OBJECTIVE**

Basically, this project is for determining areas in buildings or rooms which have high or low sound pressure level due to the sound source around the area. This project is about building acoustic analysis using finite element method. The software used is ANSYS 7.0. ANSYS 7.0 is used to model and to predict the acoustic of a typical enclosure representing a building or room. The enclosure is represented in 2-D.

By using finite element analysis and ANSYS software, one can produce a noise contour map and the pressure values. The contour map can show which area has maximum or minimum value. This can contribute in designing rooms or buildings which have a good learning environment.

Different values of frequency used as a sound source represent different types of sources. The reverberation time measurement for lecture room in that building is also important in order to investigate whether it meets the requirements of building acoustics. The most important is to provide a very comfortable place for learning process with a very low reverberation.

# CHAPTER 2 – LITERATURE REVIEW

## 2.1: General Review

The measurement of sound and its characteristics plays an important role in the development of a systematic approach to noise control. In particular, the measurement of overall sound levels can be used to determine compliance with regulations or pertinent criteria. These measurements can also be used to assess the effectiveness of various control methods and to establish realistic goals.

The measurement of sound and its characteristics plays an important role in the development of a systematic approach to noise control. In particular, the measurement of overall sound levels can be used to determine compliance with regulations or pertinent criteria. These measurements can also be used to assess the effectiveness of various control methods and to establish realistic goals. [3]

### 2.1.1: Acoustic

Acoustic mean of or relating to sound, the sense of hearing, or the science of sound and having to do with the energy of sound waves. Acoustics is the science of sound, including the generation, transmission, and effects of sound wave. Generally noise is any unwanted sound. Noise can contribute to a number of physical and psychological problems.

Sound is produced when a vibrating object causes air particles around it to vibrate. The vibrating air commonly known as sound wave moving and expanding through an area. Sound will always travel through the path of least resistance. Air is the easiest but sound waves can travel through almost any material. [4]

2.1.2: Absorption

The properties of a material composition to convert sound energy into heat thereby reducing the amount of sound energy that can be reflected. [5]

Table 2.1: Absorption coefficient - $\alpha$ - for some common materials

| Material | Sound Absorption Coefficient - $\alpha$ |
|---|---|
| Plaster walls | 0.01 - 0.03 |
| Unpainted brickwork | 0.02 - 0.05 |
| Painted brickwork | 0.01 - 0.02 |
| 3 mm plywood panel | 0.01 - 0.02 |
| 6 mm cork sheet | 0.1 - 0.2 |
| 6 mm porous rubber sheet | 0.1 - 0.2 |
| 12 mm fiberboard on battens | 0.3 - 0.4 |
| 25 mm wood wool cement on battens | 0.6 - 0.07 |
| 50 mm slag wool or glass silk | 0.8 - 0.9 |
| 12 mm acoustic belt | 0.5 - 0.5 |
| Hardwood | 0.3 |
| 25 mm sprayed asbestos | 0.6 - 0.7 |
| Persons, each | 2.0 - 5.0 |
| Acoustic tiles | 0.4 - 0.8 |

The absorption coefficient varies with the frequency of sound.

2.2: Theory- acoustic fluid fundamentals

The acoustic wave equation is given by [6]:

$$\frac{1}{c^2}\frac{\partial^2 P}{\delta t^2} - \nabla^2 P = 0 \quad \text{------} \quad (1)$$

Where: c = speed of sound $\left(\sqrt{k/\rho_0}\right)$ in fluid medium

$\rho_o$ = mean fluid density

k = bulk modulus of fluid

P = acoustic pressure (= P(x, y, z, t))

t = time

The transient dynamic equilibrium equation of interest is as follows for a linear structure [6]:

$$[M]\{\ddot{u}\} + [C]\{\dot{u}\} + [K]\{u\} = \{F^a\} \qquad (2)$$

Where: [M] = structural mass matrix

[C] = structural damping matrix

[K] = structural stiffness matrix

$\{\ddot{u}\}$ = nodal acceleration vector

Since the viscous dissipation has been neglected, Equation 1 is referred to as the lossless wave equation for propagation of sound in fluids. The discretized structural Equation 2 and the lossless wave Equation 1 have to be considered simultaneously in fluid-structure interaction problems. The lossless wave equation will be discretized in the next subsection followed by the derivation of the damping matrix to account for the dissipation at the fluid-structure interface. The fluid pressure acting on the structure at the fluid-structure interface will be considered in the final subsection to form the coupling stiffness matrix [6].

For harmonically varying pressure, i.e.

$$P = \bar{P}e^{j\omega t} \qquad (3)$$

Where: $\bar{P}$ = amplitude of the pressure

$j = \sqrt{-1}$

$\omega = 2\pi f$

f = frequency of oscillations of the pressure

2.2.1: Acoustics Fluid Matrices

$$\frac{1}{c^2}\int_{vol}\{N\}\{N\}^T d(vol)\{\ddot{P}_e\} + \int_{vol}[B]^T[B]d(vol)\{P_e\} + \rho_0\int_S \{N\}\{n\}^T\{N'\}^T d(S)\{\ddot{u}_e\} = \{0\} \qquad (4)$$

where:

c = speed of sound in fluid medium

{N} = element shape function for pressure

{N'} = element shape function for displacements

$\{P_e\}$ = nodal pressure vector

$\{u_e\} = \{u_{xe}\},\{u_{ye}\},\{u_{ze}\}$ = nodal displacement component vectors

Equation 4 can be written in matrix notation to get the discretized wave equation:

$$[M_e^P]\{\ddot{P}_e\} + [K_e^P]\{P_e\} + \rho_0[R_e]^T\{\ddot{u}_e\} = \{0\} \qquad (5)$$

Where:

$$[M_e^P] = \frac{1}{c^2}\int_{vol}\{N\}\{N\}^T d(vol) = \text{fluid mass matrix (fluid)}$$

$$[K_e^P] = \int_{vol}[B]^T[B]\, d(vol) = \text{fluid stiffness matrix (fluid)}$$

$$\rho_0[R_e] = \rho_0\int_S \{N\}\{n\}^T\{N'\}^T d(S) = \text{coupling mass matrix (fluid-structure interface)}$$

2.2.2: Absorption of Acoustical Pressure Wave

$$[M_e^P]\{\ddot{P}_e\} + [K_e^P]\{P_e\} + \rho_0[R_e]^T\{\ddot{u}_e\} = \{0\} \quad (5)$$

$$[C_e^P]\{\dot{P}_e\} = \frac{\beta}{c}\int_S \{N\}\{N\}^T d(S)\{\dot{P}_e\} \quad (6)$$

Where:

$$[C_e^P] = \frac{\beta}{c}\int_S \{N\}\{N\}^T d(S) = \text{(fluid damping matrix)}$$

Combining Equation 5 and Equation 6, the discretized wave equation accounting for losses at the interface is given by [6]:

$$[M_e^P]\{\ddot{P}_e\} + [C_e^P]\{\dot{P}_e\} + [K_e^P]\{P_e\} + \rho_0[R_e]^T\{\ddot{u}_e\} = 0 \quad (7)$$

2.2.3: Acoustics Fluid - Structure Coupling

In order to completely describe the fluid-structure interaction problem, the fluid pressure load acting at the interface is now added to Equation 2. This effect is included in FLUID29 and FLUID30 which are used for room analysis [6].

$$[M_e^p]\{\ddot{P}_e\} + [C_e^p]\{\dot{P}_e\} + [K_e^p]\{P_e\} + \rho_o [R_e]^T \{\ddot{u}_e\} = 0 \quad (7)$$

$$[M_e]\{\ddot{u}_e\} + [C_e]\{\dot{u}_e\} + [K_e]\{u_e\} - [R_e]\{P_e\} = \{F_e\} \quad (8)$$

Equation 7 and Equation 8 describe the complete finite element discretized equations for the fluid-structure interaction problem and are written in assembled form as [6]:

$$\begin{bmatrix} [M_e] & [0] \\ [M^{fs}] & [M_e^p] \end{bmatrix} \begin{Bmatrix} \{\ddot{u}_e\} \\ \{\ddot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [C_e] & [0] \\ [0] & [C_e^p] \end{bmatrix} \begin{Bmatrix} \{\dot{u}_e\} \\ \{\dot{P}_e\} \end{Bmatrix} + \begin{bmatrix} [K_e] & [K^{fs}] \\ [0] & [K_e^p] \end{bmatrix} \begin{Bmatrix} \{u_e\} \\ \{P_e\} \end{Bmatrix} = \begin{Bmatrix} \{F_e\} \\ \{0\} \end{Bmatrix} \quad (9)$$

where: $[M^{fs}] = \rho_o [R_e]^T$

$[K^{fs}] = -[R_e]$

For a problem involving fluid-structure interaction, therefore, the acoustic fluid element will generate all the sub matrices with superscript p in addition to the coupling sub matrices $\rho_o [R_e]^T$ and $[R_e]$. Sub matrices without a superscript will be generated by the compatible structural element used in the model [6].

2.2.4: Acoustics Output Quantities

The pressure gradient is evaluated at the element centroid using the computed nodal pressure values [6].

$$\frac{\partial P}{\partial x} = \left\{\frac{\partial N}{\partial x}\right\}^T \{P_e\} \quad (10)$$

$$\frac{\partial P}{\partial y} = \left\{\frac{\partial N}{\partial y}\right\}^T \{P_e\} \qquad (11)$$

$$\frac{\partial P}{\partial z} = \left\{\frac{\partial N}{\partial z}\right\}^T \{P_e\} \qquad (12)$$

where:

$\frac{\partial P}{\partial x}$, $\frac{\partial P}{\partial y}$, and $\frac{\partial P}{\partial z}$ = gradients in x, y and z directions, respectively, (output quantities PGX, PGY and PGZ)

The sound pressure level is computed by [6]:

$$L_{sp} = 20 \log\left(\frac{P_{rms}}{|P_{ref}|}\right) \qquad (13)$$

where: Lsp = sound pressure level (output as SOUND PR. LEVEL)

log = logarithm to the base 10

$P_{ref}$ = reference pressure ($20 \times 10^{-6}$)

$P_{rms}$ = root mean square pressure ($P_{rms} = P / \sqrt{2}$)

## 2.2.5: Frequency Weighting Curves

Many different noise indices were developed to assess the indoor acoustical environment; some of them were specifically designed to take into account sensitivity to different frequencies, while others were designed so as to ensure satisfactory conditions for listening. Some parameters are currently used in national and international standards; for example the A-weighted sound pressure level LeqA is employed by ISO 1996 [7]

Our hearing is less sensitive to very low and very high frequencies. In order to account for this, weighting filter's can be applied when measuring sound. The most common frequency weighting in current use is "A-weighting" providing results often denoted as dBA, which conforms approximately to the response of the human ear [4]

2.2.6: Calculation of the indoor acoustic condition

The sound transmission property of a panel is given by a quantity referred to as transmission lost- TL or sound reduction- R which defines as the loss in sound pressure levels occurs a the sound passes through the panel. The noise reduction- NR, between two space is primarily a function of the reduction of the panel which separates the noise space from the critically sensitive space, the total area of the panel and the amount of the sound absorption present in the receiving room. The smaller the area of the panel and the greater the absorption in the receiving room, the greater the noise reduction. [8]

2.2.7: Equivalent Sound Level, $L_{eq}$

If the sound level varies, the level must be sampled repeatedly over a well defined sampling period. Based on these samples, it is then possible to calculate a single value known as the Equivalent Sound Level, $L_{eq}$ which has the same energy of content as the varying sound level [9].

Suppose the A-weighted sound level $(L)$ varies with time $(t)$ as shown in figure 2.1 below. For an A-weighted, the symbol $L_{Aeq}$ is used.

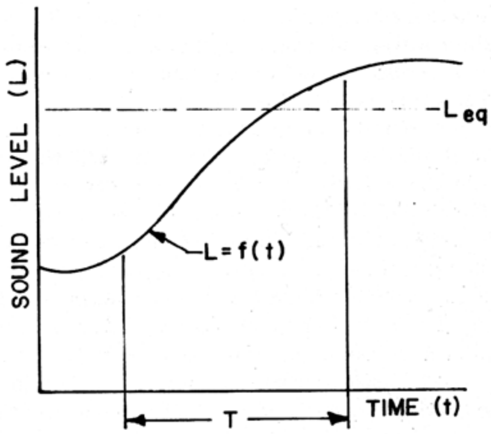

Figure 2.1: A continuous variation of sound level with time [10].

2.2.8: Sound Level Requirement for Educational Building

The magnitude of environment sound almost always varies with time. Over the years many single-numbered measures for time-varying sound levels have been developed. Some of these measures include; noise exposure forecast (NEF), composite noise rating (CNR), community noise equivalent level (CNEL), the level exceeded 90,50, or 10% of the time ($L_{90}$, $L_{50}$, $L_{10}$), and the equivalent sound level ($L_{eq}$). The Noise Control Act of 1972 names the U.S Environmental Protection Agency (EPA) as the coordinating agency for all federal agencies involved in noise research, control, and regulation. To foster uniformity and simplicity of measurement and monitoring, the equivalent sound level concept has been advanced to supersede other cumulative measures [10].

The background noise is defined by the $L_{90}$ level, as the noise level exceeded for 90% of the time and the peak level was defined as the $L_{10}$ level, as the noise level exceeded for 10% of the time [11].

Table 2.2: Yearly average for equivalent sound level, $L_{eq}$ (dBA) as requisite considering activity interference, hearing loss, and to protect against both effect for an educational building [10].

| | Measure | Indoor | | To protect against both effects | Outdoor | | To protect against both effects |
|---|---|---|---|---|---|---|---|
| | | Activity Interference | Hearing Loss Consideration | | Activity Interference | Hearing Loss Consideration | |
| Educational | $L_{eq}$ | 45 | 70 | 45 | 55 | 70 | 55 |

From table 2.2 above, we are interested in equivalent sound level value for educational environment only. The first column which is the indoor column (lecture room) requires that, to consider the activity interference, equivalent sound level, $L_{eq}$ should not exceed 45 dB. Similarly for the outdoor condition (outside the lecture room), the equivalent sound level, $L_{eq}$ should not exceed 55 dB.

Though the equivalent sound level, $L_{eq}$ is the most recommended as cumulative noise analysis, we can still make a comparison with the result obtained for the 10% noise level, $L_{10}$ which is the sound level exceeded for 10% of the time.

Table 2.3: The recommended $L_{10}$ values for different type of environment [11].

| | dBA ($L_{10}$ values) | |
|---|---|---|
| New factories | 50 | |
| Old factories not typical of the area | 55 | |
| Old factories in keeping with the area | 60 | |
| General areas in schools, offices and hospitals where speech intelligibility is important | 55 | |
| | Day-time | Night-time |
| Houses in country areas | 40 | 30 |
| Houses in suburban areas but away from main traffic routes | 45 | 35 |
| Houses in busy urban areas | 50 | 35 |

Here, we can make comparison for the data obtained with the general areas in schools, offices and hospitals where speech intelligibility is important where the $L_{10}$ value is 55 dBA.

The specific criterion for maximum background noise in lecture room is 35 dBA [12]. These specifications are consistent with long standing recommendations for good practice in acoustical design.

## 2.3: Acoustic analysis using ansys

Definition of ANSYS:

ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The forces or temperatures, or "loads," on each element are then calculated one by one using differential equations and the results integrated and tabulated. These results then can be presented in numerical or graphical form. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand.

ANSYS is the standard FEA teaching tool within the Department of Mechanical Engineering at many colleges. ANSYS is also used in Civil Engineering, Electrical Engineering, and the Physics and Chemistry departments. [13]

### 2.3.1: Generic Steps to Solving any Problem in ANSYS:

1) Build Geometry

After preliminary design of the object, construct a two or three dimensional representation of it using the work plane coordinate system within ANSYS.

2) Define Material Properties

Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.

3) Generate Mesh

At this point ANSYS understands the makeup of the part. Now define how the modeled system should be broken down into finite pieces.

4) Apply Loads

Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or thermal boundary conditions.

5) Obtain Solution

This is actually a step, because ANSYS needs to understand within what state the results must be solved for, such as a steady state, transient… etc.

6) Present the Results

After the solution has been obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots. [13]

Acoustics is the study of the generation, propagation, absorption, and reflection of pressure waves in a fluid medium. Applications for acoustics include the following:

- Sonar - the acoustic counterpart of radar

- Design of concert halls, where an even distribution of sound pressure is desired
- Noise minimization in machine shops
- Noise cancellation in automobiles
- Underwater acoustics
- Design of speakers, speaker housings, acoustic filters, mufflers, and many other similar devices.

Within ANSYS, an acoustic analysis usually involves modeling a fluid medium and the surrounding structure. Characteristics in question include pressure distribution in the fluid at different frequencies, pressure gradient, and particle velocity, the sound pressure level, as well as, scattering, diffraction, transmission, radiation, attenuation, and dispersion of acoustic waves. A coupled acoustic analysis takes the fluid-structure interaction into account. An uncoupled acoustic analysis models only the fluid and ignores any fluid-structure interaction [13].

The ANSYS program assumes that the fluid is compressible, but allows only relatively small pressure changes with respect to the mean pressure. Also, the fluid is assumed to be non-flowing and in viscid (that is, viscosity causes no dissipative effects). Uniform mean density and mean pressure are assumed, with the pressure solution being the deviation from the mean pressure, not the absolute pressure. [13]

### 2.3.2: Room acoustic analysis

This sample problem demonstrates the use of FLUID30 to predict the acoustic standing wave pattern of a typical enclosure representing a room. A sound-absorption material is located at the bottom surface of the enclosure and a vibrating structure with a cylindrical surface is located at the top right hand corner of the enclosure. This problem will determine the acoustic pressure wave pattern when the structure vibrates at an excitation of various frequencies. [13]

### 2.3.3: FLUID30

FLUID30 is used for modeling the fluid medium and the interface in fluid/structure interaction problems. Typical applications include sound wave propagation and submerged structure dynamics. The governing equation for acoustics, namely the 3-D wave equation, has been discredited taking into account the coupling of acoustic pressure and structural motion at the interface. The element has eight corner nodes with four degrees of freedom per node: translations in the nodal x, y and z directions and pressure. The translations, however, are applicable only at nodes that are on the interface [14].

### 2.4: Noise contour map

To successfully implement noise control measures, it is first necessary to obtain information about the noise levels to which people exposed. By generating a noise contour map illustrating the distribution of noise, we are provided with a graphical representation of sound pressure levels within the selected are such as in the lecture room and at the entire ground floor of the building. The noise contour map can also be used to:

- ✓ Identify plant creating particularly high sound pressure levels which may be amenable to noise reduction source.
- ✓ Locate the cause of high sound pressure levels which may be some distance from the source.
- ✓ Monitor noise emission from machines or processes to highlight the need for maintenance or repair
- ✓ Identify low-noise corridors so that the movement of people within the building can be organized to reduce unnecessary exposure.
- ✓ Check ear protection zones and monitor the use of ear protection.

## CHAPTER 3 – METHODOLOGY

### 3.1: Types of Acoustic Analysis

An acoustic analysis, available in the ANSYS/Multiphysics and ANSYS/Mechanical programs only, usually involves modeling the fluid medium and the surrounding structure. Typical quantities of interest are the pressure distribution in the fluid at different frequencies, pressure gradient, particle velocity, the sound pressure level, as well as, scattering, diffraction, transmission, radiation, attenuation, and dispersion of acoustic waves. A coupled acoustic analysis takes the fluid-structure interaction into account. An uncoupled acoustic analysis models only the fluid and ignores any fluid-structure interaction.

The ANSYS program assumes that the fluid is compressible, but allows only relatively small pressure changes with respect to the mean pressure. Also, the fluid is assumed to be non-flowing and in viscid (that is, viscosity causes no dissipative effects). Uniform mean density and mean pressure are assumed, with the pressure solution being the deviation from the mean pressure, not the absolute pressure.

3.2: Solving Acoustics Problems

Many acoustics problems can be solve by performing a harmonic response analysis. The analysis calculates the pressure distribution in the fluid due to a harmonic (sinusoidal varying) load at the fluid-structure interface. By specifying a frequency range for the load, the pressure distribution can be observed at various frequencies. Modal and transient acoustic analyses can also be performing. For this analysis, various frequency values are used as a sound source. The values used are 40Hz, 50Hz, 60Hz, 70Hz and 80Hz.

The procedure for a harmonic acoustic analysis consists of three main steps:

- Build the model.
- Apply boundary conditions and loads and obtain the solution.

- Review the results.

3.2.1: Building the Model

In this step, the job name and analysis title must specified first and then use the PREP7 preprocessor to define the element types, element real constants, material properties, and the model geometry. For this analysis, only FLUID30 is used as the elements type. The material properties are as below:

Dimension for the model:

Length = 27 ft

High = 20 ft

Depth = 1 ft

*Material 1 (walls)*

Density = 2.35 E-3 Ib/ft$^3$

Speed of sound (sonic) = 1100 ft/sec

Boundary admittance/surface absorption = 0.04

*Material 2 (floor)*

Density = 2.35 E-3 Ib/ft$^3$

Speed of sound (sonic) = 1100 ft/sec

Boundary admittance/ surface absorption = 0.7

*Material 3 (interior)*

Density = 2.35 E-3 Ib/ft$^3$

Speed of sound (sonic) = 1100 ft/sec

Boundary admittance/ surface absorption = 0.0

3.2.1.1: Harmonic Acoustic Analysis Guidelines

For a harmonic acoustic analysis:

Element Types - Four ANSYS element types are specifically designed for acoustic analyses: FLUID29 and FLUID30 are used to model the fluid portion of 2-D and 3-D models respectively. FLUID129 and FLUID130, companion elements to FLUID29 and FLUID30, are used to model an infinite envelope around the FLUID29 and FLUID30 elements. Use these element types to model the fluid portion, and then use a corresponding structural element (PLANE42, SOLID45, etc.) for the solid. Only FLUID29 and FLUID30 elements can be in contact with structural elements (either on the inside or outside of the structure); FLUID129 and FLUID130 can contact only the FLUID29 and FLUID30 elements, and not the structural elements directly.

3.2.1.2: FLUID29 and FLUID30

For acoustic elements that are in contact with the solid, be sure to use KEYOPT (2) =0, the default setting that allows for fluid-structure interaction. This results in unsymmetric element matrices with UX, UY, UZ, and PRES as the degrees of freedom. For all other acoustic elements, set KEYOPT (2) =1, which results in symmetric element matrices with the PRES degree of freedom. (See Figure 3-1.) Symmetric matrices require much less storage and computer time, so use them wherever possible.

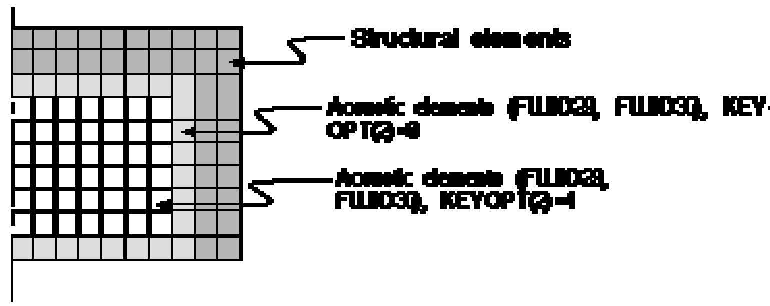


Figure 3-1 Example of a 2-D acoustic model (fluid within a structure) [15]

3.2.2: Meshing the Model

A typical meshing procedure using the 2-D infinite acoustic elements follows. The procedure is the same with 3-D elements. For a structural component, the structural elements must lie next to the FLUID29 elements, and cannot lie next to the infinite fluid elements (FLUID129).

The infinite elements perform well for low as well as high frequency excitations. Numerical experiments have determined that the placement of the absorbing elements at a distance of approximately $0.2\lambda$ beyond the region occupied by the structure or source of vibration can produce accurate solutions. Here $\lambda=c/f$ is the dominant wavelength of the pressure waves. c is the speed of sound (SONC) in the fluid and f is the dominant frequency of the pressure wave.

3.2.3: Applying Loads and Obtaining the Solution

This step is about defining the analysis type and options, apply loads, specify load step options, and initiate the finite element solution. The next few sections explain how to do these tasks. For this analysis:

Analysis type = harmonic

Load = loads applied at the top right hand corner of the area in frequencies (40Hz, 50Hz,60Hz, 70Hz and 80Hz) and substeps

3.2.3.1: Enter the SOLUTION Processor

Enter the SOLUTION processor by choosing GUI path Main Menu>Solution or by executing the /SOLU command.

3.2.3.2: Define the Analysis Type

Using either the GUI or a set of commands, define the analysis type and analysis options. New Analysis must be chosen because restarts are not valid in a harmonic response analysis. To apply additional harmonic loads, do a new analysis each time (or use the "partial solution" procedure described in the ANSYS Basic Analysis Procedures Guide).

3.2.3.3: Define Analysis Options

To specify the solution method, use one of the following: Although full, reduced, or mode superposition methods are options, choose the full method because it alone can handle unsymmetrical matrices.

3.2.3.4: Apply Loads on the Model

A harmonic analysis, by definition, assumes that any applied load varies harmonically (sinusoidally) with time. To completely specify a harmonic load in an acoustic analysis, two pieces of information are usually required: the amplitude and the forcing frequency. The amplitude is the maximum value of the load. The forcing frequency is the frequency of the harmonic load (in cycles/time). Specify it later as a load step option with the HARFRQ command (Main Menu>Solution> Time/Frequenc>Freq & Substeps).

Table 3-1 shows all possible loads for a harmonic acoustic analysis and the commands to define, list, and delete them. Notice that except for inertia loads, loads can be define either on the solid model (keypoints, lines, and areas) or on the finite element model (nodes and elements).

Table 3.1 Loads Applicable in an Acoustic Analysis

| Load Type | Category | Cmd Family | GUI Path |
|---|---|---|---|
| Displacement (UX,UY,UZ), Pressure (PRES) | Constraints | D | Main Menu>Preprocessor>-Loads-> Apply>Displacement or Potential<br><br>Main Menu>Solution>Apply> Displacement or Potential |
| Force (FX,FX,FZ), Moment (MX,MY,MZ), Flow loading | Forces | F | Main Menu>Preprocessor>-Loads-> Apply>Force/Moment<br><br>Main Menu>Solution>-Loads-Apply>Force/Moment |
| Pressure (PRES)<br>Impedance (IMPD)<br>Fluid-structure interaction flag (FSI) | Surface Loads | SF | Main Menu>Preprocessor>-Loads-> Apply>*load type*<br><br>Main Menu>Solution>Apply>load type |
| Gravity, Spinning, etc. | Inertia Loads | ACEL, OMEGA, DOMEGA, CGLOC, CGOMEGA, DCGOM, IRLF | Main Menu>Preprocessor>-Loads-> Apply>*load type*<br><br>Main Menu>Solution>Apply>*load type* |

## 3.3: Applying Loads Using the GUI

Access all loading operations except List (see below) through a series of cascading menus. From the Solution menu, choose the operation (apply, etc.), then the load type (displacement, force, etc.), and then the object (keypoint, etc.) to which the load is applied.

For example, to apply a displacement load to a line, follow this GUI path: Main Menu>Solution>Apply>Displacement>On Lines

To list loads, use this GUI path: Utility Menu>List>Loads>load type

### 3.3.2: Load Types

Displacements (UX, UY, UZ) and pressures (PRES) These are DOF (degree-of-freedom) constraints. For example, specify zero displacements at a rigid fluid-structure interface. Specify non-zero displacements, but remember that they are assumed to be harmonic. Usually, specify zero pressures at free fluid boundaries (where the fluid is not enclosed, such as at an opening).

*Forces (FX, FY, FZ) and moments (MX, MY, MZ)*

Usually, specify these loads on the solid portion of the model to "excite" the fluid.

*Pressure (PRES)*

Surface loads can be specifying on the solid portion instead of forces and moments.

*Impedance (IMPD)*

These are not really loads but indicate surfaces that absorb sound. Specify the degree of sound absorption as the material property MU (boundary admittance or absorption coefficient).