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INDUSTRIAL NOISE SERIES

Part IV

MODELING

SOUND PROPAGATION

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MODELING SOUND PROPAGATION

1. SOUND PROPAGATION

A major challenge in acoustics is to accurately predict what the sound level will be at some location, far or near. Sound propagation modeling and prediction span from the simplest calculation to highly sophisticated computer programs. This treatise presents a basic overview of sound propagation that is typically performed for most industrial noise applications.

We are principally interested in two aspects of sound: aerodynamic propagation (inlets and exhausts radiating noise) and structural radiation from surfaces (walls, roofs, etc). The latter being the more challenging to model but is principally a function of the source of noise contained within the structure.

Aerodynamic sources are fairly easy to model, sound that is directly radiating into the environment from some opening. Breakout noise and sound radiation from a structure is a bit more complicated. There are two basic excitation forms of sound radiation from a structure: vibratory motion of the structure from excitation; and, sound being directly transmitted through the structure (breakout noise). In both cases, it is critical that information on how the equipment operates and the sound power level be provided. The sound power level is necessary for calculating the sound level at some location. Sound power level (PWL) must be supplied for the octave bands of interest, generally the nine bands from the 31.5 Hz band through the 8k Hz. Sometimes sound data is provided for the 27 one-third octave bands. An example of octave band sound power level is presented in the following table.

Table I – Example listing of Sound Power Level, dB re: 1 pico-watt

OBCF, Hz	31.5	63	125	250	500	1000	2000	4000	8000
PWL, dB	142	138	135	128	118	111	105	103	95

OBCF: octave band center frequency

Sound power levels are unique to every piece of equipment (source of noise). The sound level at some location is the combination of all the possible noise sources. Large industrial plants can have several dozen sources of noise and each is modeled and combined with all the other equipment to arrive at the total sound level at some specified location.

2. SOUND FIELDS

In order to predict or model noise from equipment we need to understand, or better, define the sound fields and the predicted sound level associated with those fields. The near field, far field, free field and reverberant field are the most common. The regions that describe the sound fields and sound propagation are illustrated in Figure 1.

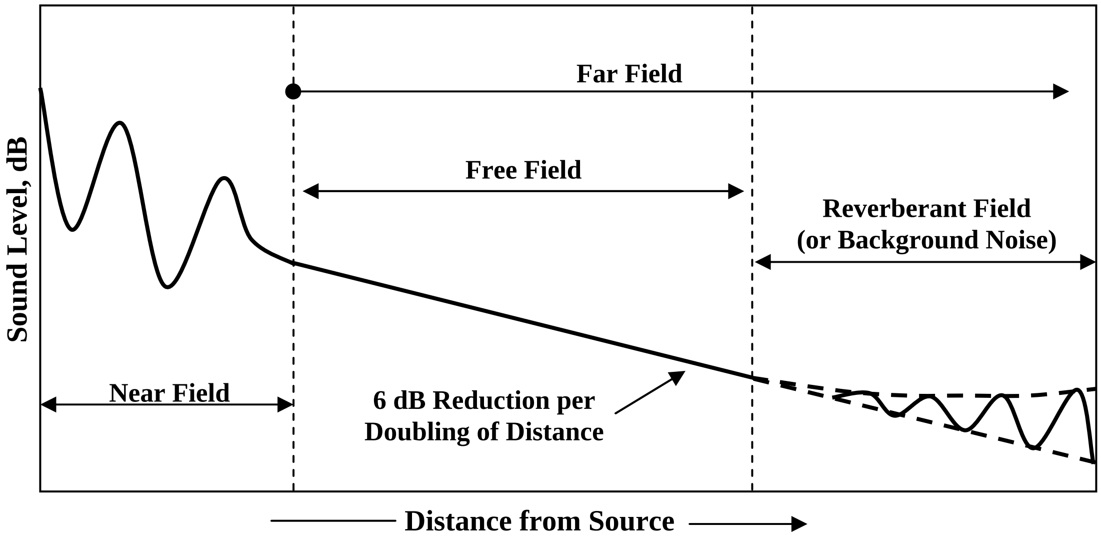

FIGURE 1 - DEFINITION OF SOUND FIELDS

The near field region is probably the most difficult to predict as this describes the region where noise propagation is not well developed and construction techniques and equipment installation details that are generally unknown affect the amount of noise around the equipment or structure.

The far field starts where the sound field becomes more stable and propagation is fairly uniform. This location is frequency (wavelength) dependent and is usually two to four major source dimensions (width and height as you look at the source) away from the noise source.

The free field describes where sound freely propagates and spreads uniformly. The sound level decreases approximately six decibels for every doubling of distance. As you get farther away from the source the decay rate starts to flatten out once the sound from the source approaches the ambient or background sound level as illustrated in the right section of the figure.

The reverberant field occurs where freely propagating sound waves are reflected back from a wall, a ceiling, or other surfaces again causing variation in sound levels as illustrated.

3. PROPAGATION MODELING OF SOUND

The radiation of sound comes from various sources: the aero/fluid-dynamic path from a fan, engine, turbine or flow regulating device; or, from the structural path from the engine body, duct wall, pipe wall, valve body, or enclosure wall. ISO 9613-2, *Acoustics – Attenuation of sound during propagation outdoors*, is the standard used for modeling outdoor sound propagation and predicting far field sound levels. Many computerized prediction and modeling programs are based on this standard.

The radiation of sound may be generally described (modeled) by the following expression,

$$L_p = L_W + 10\,Log\left(\frac{Q}{4\pi r^2}\right) - \sum A_i \quad \text{dB re: } 20\mu\text{Pa} \tag{1}$$

This method is also commonly referred to as *ray tracing*, that is, the sound ray (path) is modeled by a set of geometric terms ($Q/4\pi r^2$) and losses (ΣA_i). Equation (1) is the basic form and predicts the sound level L_p at a distance *r* (meters), where *Q* defines the reflective surfaces that are around the source of noise having a sound power, L_W. ΣA_i is the term used to account for all the elements that can affect the sound level (directivity, atmospheric loss, barriers, ground effects, trees, etc.). See ISO 9613-2 for the full description of modeling sound propagation.

Absent from Equation (1) is the functional descriptor for frequency. This expression is applied for each frequency band of interest. Each source of noise may have up to ten octave bands or up to 27 one-third octave bands. Equation (1) is applied to each band, see Table I as an example, and the overall sound level determined from the all the octave or one-third octave band sound pressure levels.

Q accounts for the reflective planes that bound the source of noise. These planes act as reflectors focusing the sound or bounding the sound to a certain area. It is also referred to as the solid angle of propagation (D_Ω) and by other descriptors. For general modeling, *Q* has the following values,

Q	Boundary Conditions
1	Point source freely radiating in all directions (chimney)
2	Point source with a single reflective plane (ground)
4	Point source with two reflective surfaces
8	Point source with three reflective surfaces

More specific directivity values may be used if known but this is seldom the case. In the case of complex or large machinery the sound power may be distributed with each “sub-source” having its own directivity value to account for reflective surfaces.

Directivity of a specific nature may be introduced if known which is a measure of the sound level relative to the averaged sound level in a given direction and is called the Directivity Index,

$$DI_\theta = L_{p\theta} - \overline{L_p} \quad \text{dB} \tag{2}$$

Where, $\overline{L_p}$ is the predicted or averaged sound level at the distance *r* versus the measured sound, $L_{p\theta}$. This enables the use of a specific Directivity Index applicable to the source of noise in order to predict sound levels from the source in a specific direction. Directivity is critically important in the level of sound exiting a stack or chimney as directed towards a receptor location. The directivity value is incorporated into ΣA_i term in Equation (1).

You may have noted in the listing above that the term, *point source*. In modeling, each source of noise is modeled as a discrete point radiating sound. This may seem puzzling for a machine that is 3 meters long, 4 meters wide and 2 meters high. Large equipment at large distances, act like a small point of noise. It is when modeling the sound level in the near field that it becomes complicated. In these cases the equipment is divided into small areas and the sound power level is distributed over the surface area of the equipment. This is where the accuracy of the predicted sound level can be off several decibels.

Equation (1) can be expanded into the more familiar form:

$$Lp = L_W + 10 Log(Q) - 10 Log(4\pi r^2) - \sum A_i \quad \text{dB re: } 20\mu\text{Pa} \tag{3a}$$

If we assume Q=2 (typically represents the ground plane) and with further simplification:

$$Lp = L_W + 3 - 10 Log(4\pi) - 20 Log(r) - \sum A_i \quad \text{dB re: } 20\mu\text{Pa} \tag{3b}$$

$$Lp = L_W - 20 Log(r) - 8 - \sum A_i \quad \text{dB re: } 20\mu\text{Pa} \tag{3c}$$

Where *r* is meters and in many cases ΣA_i is zero if the distance (r) is relatively close to the source and there are no intervening barriers or obstructions.

$$Lp = L_W - 20 Log(r) - 8 \quad \text{dB re: } 20\mu\text{Pa} \tag{3d}$$

This form is found in many texts. If the distance term *r* is in feet then,

$$Lp = L_W - 20 Log(r) + 2.3 \quad \text{dB re: } 20\mu\text{Pa} \tag{4}$$

Note that the term, 20 Log (r) is the distance spreading of sound energy and if the distance r is doubled the spreading loss increases by 6 dB.

These equations give the resulting sound pressure at some distance dependent upon the sound power and directivity. In noise control, the sound power is typically reduced by some method of mitigation or silencing.

4. Modeling Sound Propagation

There are dozens of technical books on sound propagation but ISO 9613-2 is the only standard that encompasses a standardized method for calculating sound propagation. It is used worldwide and is the basis for most all sophisticated computer modeling programs.