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INDUSTRIAL NOISE SERIES

PART IV: MODELING SOUND PROPAGATION

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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: propagation from inlets and exhausts (gas path) 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 or duct.

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 transmitted through the structure (breakout noise). Now, the sound does not really “go through” a wall or structure but the sound energy excites the structure on the source side and the structure then re-radiates that energy out to the receiver side but at a reduced level. For very thin walls, there is not much resistance to the sound wave and at very low frequencies (that have very large wavelengths) can cause walls or structures to act like a harmonic bellows.

In all applications, it is critical to know how the equipment operates, its sound power level, and what the principal forcing frequencies are. 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 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.

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.

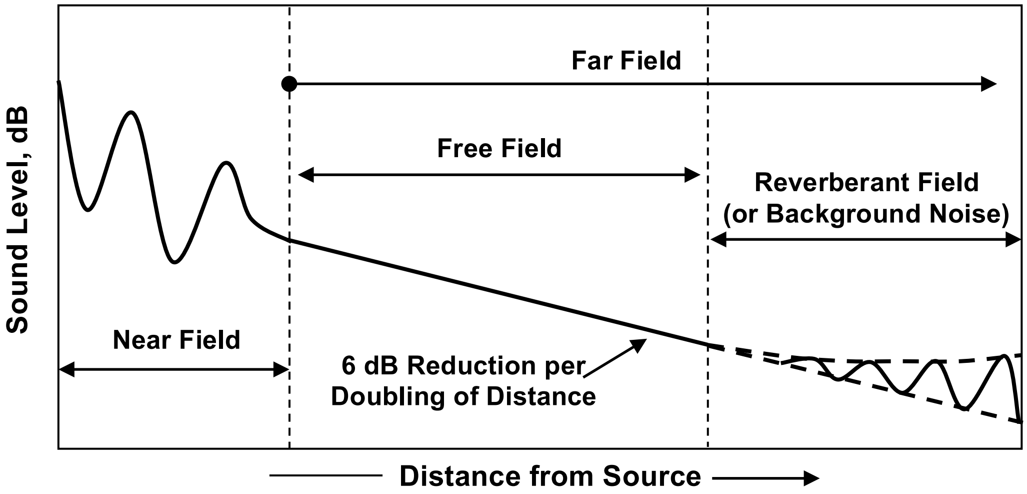

Figure 1 - Definition of Sound Fields

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 and may 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.

SOUND SOURCES

The conventional classification of sound sources is they are one of three geometries: a point source, a line source or an area source. The challenge is, so what do these mean and how are they modeled.

- A point source is sound emitted from a tall chimney, small aperture, or even an airplane. The sound level typically drops six decibels for every doubling of distance (in the free field).
- A long road, duct, pipe or similar object is a line source. The sound level typically drops three decibels for every doubling of distance (in the free field).
- An area source is most challenging as it rarely radiates sound in a homogeneous manner; it has hot spots and cold spots when it comes to sound radiation.
- Any object becomes a point source when the distance between the source and receiver is large.

In modeling, all sources are modeled as a point source as will become evident in the next section. To create point sources, line and area sources are systematically divided into small discrete segments or areas and the sound power level distributed among the discrete points on an energy basis; to cross check, when you sum the sound power levels of all the discrete elements it should equal the total sound power level.

One advantage of modeling an area source as an array of points is it will provide an estimate of near field sound levels but be cautious as the spreading loss in the near field is only two or three decibels per doubling of distance until the far field boundary is met.

It is critically important to know the sound power level (PWL) of the source. The general method for calculating PWL is to define measurement planes that encompass the equipment (*A*) where the sound pressure levels (SPLs) are measured at defined array locations. The SPLs are averaged and incorporate the measurement area to arrive at the sound power level by,

$$L_W = L_p + 20 Log\left(A\right) \quad \text{dB re: one pico-Watt} \qquad (1)$$

ISO 3740[1] is a guideline in selecting an appropriate protocol for determining sound power level of various equipment types. Also, there are specialized ISOs for industrial plants and specialized equipment.

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[1] ISO 3470:(Year), Acoustics – Determination of sound power levels of noise sources – Guidelines for the use of basic standards.

SOUND PROPAGATION MODEL

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 propagation of sound may be generally described (modeled) using the following expression,

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

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 is used to calculate the sound level L_p at a distance r (meters), where *Q* defines the reflective surfaces (boundary conditions) 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.).

Absent from Equation (2) 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 (2) 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. Modeling may even be done on a narrowband basis. The more discrete the frequency, the more accurate the modeling; octave band analysis has largest inherent variance because it is broadband when most machinery noise is discrete.

Q accounts for the reflective planes or boundaries around the source of noise. These planes act as reflectors focusing the sound into to a certain direction. It is also referred to as the solid angle of propagation (D_Ω) and 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 (floor & wall)
8	Point source with three reflective surfaces (floor corner)

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,

$$DI_\theta = L_{p\theta} - \overline{L_p} \quad \text{dB} \qquad (3)$$

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 (2).

In noise control, it is always convenient to develop short cuts and simplify the process by separating constants and variables. Equation (2) can be expanded into the more familiar form:

$$Lp = L_W + 10Log(Q) - 10Log\left(4\pi r^2\right) - \sum A_i \quad \text{dB re: 20mPa} \qquad (4a)$$

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

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

$$Lp = L_W - 20Log(r) - 8 - \sum A_i \quad \text{dB re: 20mPa} \qquad (4c)$$

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.

$$Lp = L_W - 20Log(r) - 8 \quad \text{dB re: 20mPa} \qquad (4d)$$

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

$$Lp = L_W - 20Log(r) + 2.3 \quad \text{dB re: 20mPa} \qquad (4e)$$

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 of the source is typically reduced by some method of mitigation or silencing.

As a side note, accuracy in reporting decibels to tenths or hundreds is not warranted as the expected variation in sound level is at least three decibels just from the noise sources alone and at large distances atmospheric conditions greatly affect the results.