McGill AirFlow's Duct System Design Guide

Design Advisory

Design Advisory #8: CAS-DA8-2004

What's that Noise?

It happens to all of us. You're sitting in a public facility such as a restaurant when suddenly the air conditioning kicks on with a vengeance and the roar of the unit's fan effectively drowns out the conversation of your dining companions. "They need to do something about that noise," someone shouts over the din. Or you're in a customer's office having what you believe is a private, closed-door meeting when you distinctly hear laughter and talking emanating from the register over the customer's desk. You'd swear they were in the office with you. Where's the noise coming from? And more importantly, if you can hear them, can they hear you?

Unfortunately, scenarios like those are all too familiar. Far too often, the acoustics of a duct system is an afterthought if dealt with at all. It is frequently viewed as a luxury rather than a necessity. Combine this with the HVAC industry's general lack of acoustical knowledge and expertise, and its over reliance on manufacturers' data instead of analysis to compensate for it, you can easily understand why there are many noisy duct systems out there.

Controlling duct system noise levels should be an important design criterion for creating quality working environments. Noisy duct systems are not only annoying, but can affect the ability to hear verbal communication and be detrimental to the learning process in schools. So it is becoming even more important for engineers and designers to address those special acoustical issues duct systems present.

How are your acoustics design skills? You've probably heard of decibels or dB but weren't sure about the meanings of sound pressure and sound power. You may have seen RC and NC numbers but didn't know the difference. It is important to understand these concepts when designing a duct system. Not only do occupants need the required amount of air at the desired temperature and humidity, they also require a reasonably quiet environment in which to work.

For example, suppose you are designing a duct system for an office building. Will you need silencers or lined duct or both to attenuate the noise, and if so, how many or how much? Should you only specify products with the best published performance data? How do you analyze the system? These and other questions can be answered after reading the next four chapters in McGill AirFlow's *Duct System Design Guide*. But before we discuss the more advanced topics, it is necessary to understand some fundamental concepts regarding acoustics.

This installment of the *Duct System Design Guide,* "Chapter 7: Acoustical Fundamentals", covers the basics of acoustics. Beginners will appreciate the simplicity of the material and will learn about the differences between sound pressure and sound power, the relationship between wavelength and frequency, adding sound levels, and the definition of loudness and A-weighting. Chapter 7 provides the terminology and concepts important to understanding duct system acoustics, which are covered in Chapters 8 through 10.

Duct System Design Guide

$69.00 value!

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McGill AirFlow
Corporation

2400 Fairwood Avenue
Columbus, OH 43207
614/443-5520, Fax: 614/542-2620
E-mail: mafengineering@mcgillairflow.com

CHAPTER 7: Acoustical Fundamentals

7.1 Overview

The complete design of an air handling system requires that acoustical aspects be considered. It is not sufficient to simply deliver the proper volume flow rate at a design pressure. It must be done without creating excessive noise levels or tonal components.

Our discussion of acoustical air handling systems begins with a presentation of some fundamental acoustical concepts. An understanding of the fundamentals is necessary to analyze, evaluate, and remedy noise problems. In this chapter, sound power, sound pressure, decibels, frequency, loudness, and weighting are defined. **Chapter 8**, "Duct System Acoustics" includes a review of fan noise, natural attenuation, and generated and radiated duct noise.

Chapter 9 discusses room acoustics, including room characteristics and the criteria for determining allowable noise levels for various occupancy/use situations. Air terminal noise and design criteria are also covered.

Chapter 10 pulls everything from the previous chapters together and guides the designer in the proper steps to perform an acoustical analysis of a duct system.

7.2 Sound Power and Sound Pressure

The terms *sound power* and *sound pressure* sound similar, and they can be confusing to those not familiar with acoustics. Sound power, as the name implies, is a quantification of the actual acoustical power generated by a sound source. It is expressed in the power unit of watts. Sound power cannot be directly measured.

Sound pressure is a measurable fluctuation of the ambient air pressure generated by a sound source. It is expressed in the pressure unit of *Newtons per square meter* (or *Pascals*). The measured sound pressure will depend on a number of factors, including the magnitude of the sound power, the pressure measurement location with respect to the source, and the conditions along the propagation path from the source to the measurement location.

Have you ever noticed a vacuum cleaner sounding louder in a bathroom than say, the bedroom or outside? Or that it is louder nearer to it than far away? The vacuum cleaner has a constant noise generating ability (constant sound power), but the noise heard (sound pressure) is dependent on the environment and the proximity to the unit.

The range of possible sound power and sound pressure magnitudes is very large. For example, the sound power of a very faint noise at the lower limit of human audibility is 0.000000000001 (1×10^{-12}) *watts*. The sound power generated by a Saturn V rocket at lift-off is on the order of 100,000,000 ($1 \times 10^{+8}$) *watts*. Similarly, sound pressures can range from 0.00002 (2×10^{-5}) *Pascals* to 100,000 ($1 \times 10^{+5}$) *Pascals*.

Obviously, working with these very large and very small numbers would be very cumbersome, and since our ears don't hear variations in sound unless there are large differences in sound pressure, a logarithmic definition of sound power and sound pressure is used. When expressed in this fashion, the quantities are known as sound power level (abbreviated PWL or Lw) and sound pressure level (abbreviated SPL or Lp). The unit for both is the *decibel*. See **Equations 7.1** and **7.2** for definitions of sound power level and sound pressure level, respectively.

$$Lw = 10 \log_{10} \left(\frac{W}{Wref} \right)$$ **Equation 7.1**

where:

Lw = Sound power level (*dB*)

W = Sound power of the sound source (*watts*)

$Wref$ = Standard reference sound power (1×10^{-12} *watts* or 1 *picawatt*)

$$Lp = 10 \log_{10} \left(\frac{P}{Pref} \right)^2$$ **Equation 7.2**

where:

Lp = Sound pressure level (*dB*)

P = measured sound pressure (N/m^2 *or Pascals*)

$Pref$ = Standard reference sound pressure (2×10^{-5} *Pascals*, which is the threshold of youthful hearing)

Most people have some familiarity with sound levels measured in decibels. The sound level meter directly measures the local sound pressure through the use of a pressure transducer (microphone). In simple terms, the meter's pressure reading is converted to a sound pressure level using Equation 7.2.

Table 7.1 presents some typical sound sources and their approximate sound pressure levels.

Table 7.1
Sound Source and Sound Pressure Level

Source	**Lp** (*dB*)
Threshold of Hearing	0
Whisper	30
Normal Speech	60
Passing Truck	100
Pipe Organ (sforzando)	130
Jet Engine (near field)	160

Current governmental regulations state that continued exposure to sound pressure levels in excess of 85 *dB* can result in hearing impairment. Any exposure to levels exceeding 140 *dB* can result in permanent hearing damage.

Since sound levels are logarithmic quantities, an increase or decrease of only a few decibels is significant. For example, a sound pressure level change of 6 *dB* represents a doubling (or halving) of the sound pressure. Our ears, however, will not detect this change as a doubling or halving of the subjective loudness of the sound. Subjective reactions to changes in sound level are summarized in **Table 7.2**.

Table 7.2
Subjective Reactions

Change from Ambient Level	Subjective Reactions
+/- 1 *dB*	Not Detectable
+/- 3 *dB*	Just Detectable by Most People
+/- 10 *dB*	Perceived as Doubling/Halving of Loudness

Sound levels, whether it is sound pressure or sound power, cannot be added directly because they are logarithmic quantities. For example, two noise sources individually producing a sound pressure of 100 *dB* at a certain point in space will not produce 200 dB when operated simultaneously. Actually, the combined sound pressure level is 103 *dB*. The 100 dB sound pressure level is the resultant of 2 *Pascals* of sound pressure as derived in the following equation:

$$Lp = 10\log_{10}\left(\frac{2}{2 \text{ x } 10^{-5}}\right)^{2} = 100 \text{ dB}$$

Adding two 100 dB sound pressures levels logarithmically is as follows:

$$Lp = 10\log_{10}\left[\left(\frac{2}{2 \text{ x } 10^{-5}}\right)^{2} + \left(\frac{2}{2 \text{ x } 10^{-5}}\right)^{2}\right] = 103 \text{ dB}$$

therefore:

$$\sum Lp = 10\log_{10}\sum\left(\frac{P}{Pref}\right)^{2} \qquad \textbf{Equation 7.3}$$

Combining sound pressure or sound power levels can involve extensive calculations. However, the following rule-of-thumb guidelines are helpful in making fairly accurate manual calculations.

Determining the difference between two of the levels and adding the adjustments shown in **Table 7.3** to the higher of the two levels can combine any number of sound levels.

Table 7.3
Simplified Decibel Addition

Difference in Levels	Add to Higher Level
0 - 1 *dB*	3 *dB*
2 - 4 *dB*	2 *dB*
5 - 9 *dB*	1 *dB*

Whenever the difference between two sound levels is 10 *dB* or more, the louder level masks the quieter source and there is no contribution to the overall level by the second source. **Sample Problem 7-1** provides an example of decibel addition.

Sample Problem 7-1

A listener is simultaneously subjected to the following sound pressure levels: 51 dB, 53 dB, 49 dB, 45 dB, 36 dB, 31 dB, 25 dB, and 24 dB. What is the overall sound pressure level?

Answer:

The sound levels are added in groups of two, in accordance with **Table 7.3** and the results of these groups are then coupled in like manner until a single sound level is attained. The additions can be carried out in any order and results should be identical (or should vary by no more than 1 *dB*).

(51 + 53) *dB* = 53 + 2 = 55 *dB*
(49 + 45) *dB* = 49 + 2 = 51 *dB*
(36 + 31) *dB* = 36 + 1 = 37 *dB*
(25 + 24) *dB* = 25 + 3 = 28 *dB*

Adding these results together:

(55 + 51) *dB* = 55 + 2 = 57 *dB*
(37 + 28) *dB* = 37 + 1 = 38 *dB*

Finally, (57 + 38) *dB* = 57 + 0 = 57 *dB*, the overall level.

7.3 Frequency

The *frequency* of a sound is determined by the number of sound waves (pressure fluctuations) produced per unit of time. Frequency can be correlated to the *pitch* of the sound and is measured in *cycles per second* or *Hertz* (*Hz*). Humans are capable of hearing sounds from about 20 *Hz* to 20,000 *Hz*.

As a point of reference, middle C on a piano keyboard has a frequency of approximately 260 *Hz*. Moving up the keyboard, each octave C will have a frequency twice the value of the lower octave. Similarly, moving down the keyboard, each octave C will have a frequency one half that of the upper octave. This relationship is true regardless of which tone is selected as a starting point.

Frequencies which are important from an acoustical standpoint can be grouped into octave bands, each with a defining center frequency that is twice the frequency of the next lower band center frequency and one half the frequency of the next higher band center frequency. The eight octave bands are shown in **Table 7.4**.

Table 7.4
Octave Bands

Band No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Range (*Hz*)	45 to 90	90 to 180	180 to 355	355 to 710	710 to 1,400	1,400 to 2,800	2,800 to 5,600	5,600 to 11,200
Center Frequency (*Hz*)	63	125	250	500	1,000	2,000	4,000	8,000

Note that in the higher frequencies, the octave band ranges are much wider than in the lower frequencies. This indicates that our ability to distinguish constant increment frequency differentials is reduced as frequency increases.

7.4 Wavelength

The wavelength of sound is the distance between successive points of compression or rarefaction in the sound carrying medium, usually air. Two sound waves are drawn in **Figure 7.1**. Both waves are of the same frequency, one cycle per second or 1 Hz. One of the waves has a higher amplitude than the other wave, and therefore, is louder.

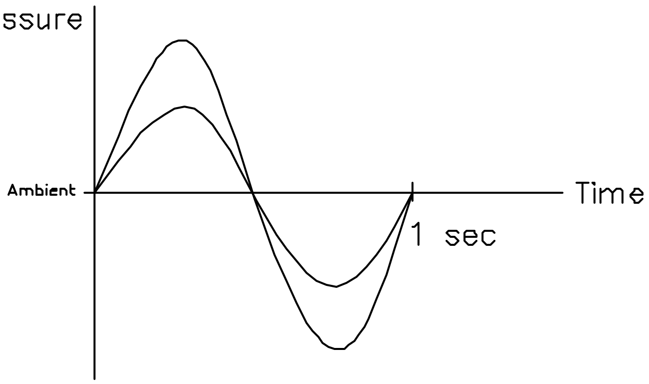

Figure 7.1
Graph of Two Sound Waves

The relationship between wavelength and frequency is shown in **Equation 7.4**.

$$l = \frac{c}{f}$$ **Equation 7.4**

where,

l = Wavelength (ft)

c = speed of sound ($feet\ per\ second$)

f = frequency of wave (Hz)

As discussed in **Section 7.3** the frequency of a sound is determined by the number of sound waves produced per unit of time. Since one complete wavelength is equal to one cycle, and we use the “second” as our unit of time measurement, a 63 Hz frequency sound has 63 wavelengths pass a point every second. This means that low frequency sounds have longer wavelengths than high frequency sounds. See **Table 7.5** for the wavelengths of the octave band center frequencies at room temperature. Since the speed of sound is a function of air density, changes in temperature result in changes in wavelength.

Table 7.5
Wavelengths of Octave Band Center Frequencies

Frequency (Hz)	Wavelength (feet)
63	17.9
125	9.0
250	4.5
500	2.3
1000	1.1
2000	0.6
4000	0.3
8000	0.1

7.5 Loudness

Loudness can be defined as the intensive attribute of an auditory sensation. It is a function of both sound pressure level and frequency. Various metrics have been created to measure loudness, but all recognize that low frequency noise is more tolerable than similar levels at higher frequencies.

As a result of numerous surveys made with a wide range of human subjects, equal loudness contours have been created which provide an indication of the actual pure tone sound pressure levels at various frequencies which are judged to be equal in loudness to a reference tone at 1,000 Hz. For example, in the first octave band (63 Hz), a 61 dB tone is considered to have the same loudness as a 40 dB tone at 1,000 Hz. In the seventh octave band (4,000 Hz), a 33 dB level is judged to be equal to the same 40 dB tone at 1,000 Hz. Thus the frequency of a sound will have a substantial bearing on how loud it is perceived to be.

Figure 7.2 presents typical equal loudness contours.

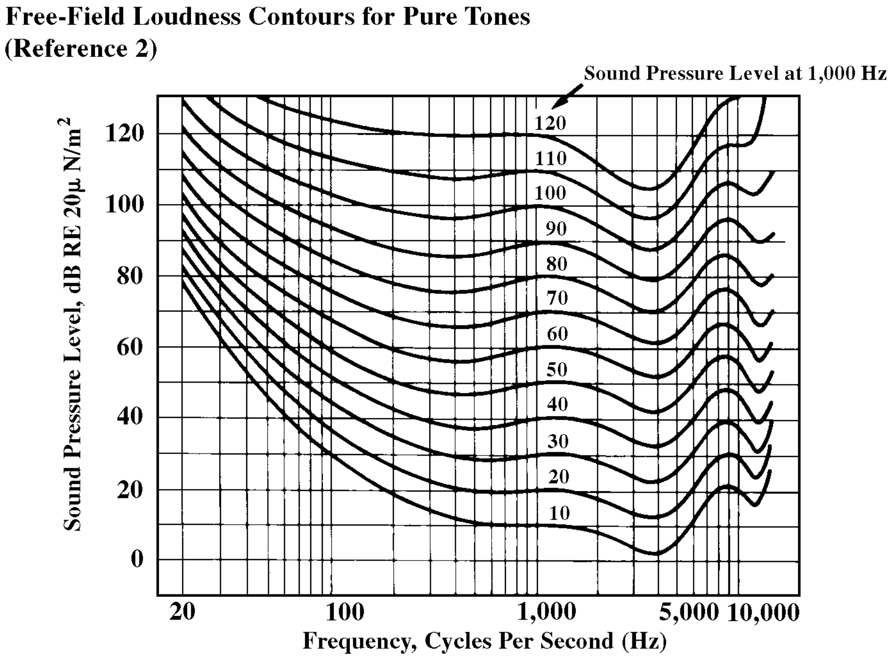

Figure 7.2
Equal Loudness Contours

7.6 Weighting

When sound pressure levels are measured in the various octave bands, it is often useful to *weight* the levels in accordance with their perceived contribution to loudness. Since, as indicated above, humans are less sensitive to noise with lower frequencies, the measured levels at these frequencies are reduced to reflect this. High frequency noises contribute substantially to annoyance and should not be reduced from their measured levels. In fact, the human ear is so sensitive to noises at 2,000 and 4,000 *Hz* that the most common weighting system, A-weighting, actually increases these levels slightly.

The A-weighting system requires that adjustments be made to the measured sound pressure levels at each frequency, in accordance with their relative contribution to annoyance or loudness. In this way, the A-weighted sound levels will more nearly reflect the response characteristics of the human ear. **Table 7.5** presents the A-weighting adjustments as a function of frequency.

Table 7.5
A-Weighting

Octave Band Number	Frequency (Hz)	Adjustment (dB)
1	63	-26
2	125	-16
3	250	-9
4	500	-3
5	1,000	0
6	2,000	+1
7	4,000	+1
8	8,000	-1

Sample Problem 7-2

Refer to the unweighted sound levels given in ***Sample Problem 7-1****. Assume that these are the eight-octave band levels measured for a single sound source. Determine the overall A-weighted sound pressure level of the source.*

Answer:

First, each of the frequency components must be A-weighted. Next, they can be added, using decibel (logarithmic) addition, in a similar fashion to the previous problem. The A-weighted levels are as follows:

OB	Unweighted Lp (dB)	A-weight Adjustment (dB)	A-weighted Lp (dBA)
1	51	-26	25
2	53	-16	37
3	49	-9	40
4	45	-3	42
5	36	0	36
6	31	+1	32
7	25	+1	26
8	24	-1	23

Now, add the A-weighted frequency components to arrive at an overall A-weighted Lp.

(25 + 37) dB = 37 + 0 = 37 dB
(40 + 42) dB = 42 + 2 = 44 dB
(36 + 32) dB = 36 + 2 = 38 dB
(26 + 23) dB = 26 + 2 = 28 dB

Adding these results together:

(37 + 44) dB = 44 + 1 = 45 dB
(38 + 28) dB = 38 + 0 = 38 dB

Finally, (45 + 38) dB = 45 + 1 = 46 dBA, the overall A-weighted level.

Because the A-weighting system is a relatively simple metric, and because it accounts for the sensitivity of human hearing as a function of frequency, the Occupational Safety and Health Administration (OSHA) adopted its use for setting noise limits for noisy working environments. In regard to working conditions, specific requirements and guidelines are located in OSHA Standard 29CFR, Part 1910, Subpart G "Occupational Health and Environmental Control"

Many local codes and regulations have adopted guidelines similar to OSHA. Almost all outdoor noise regulations utilize A-weighting as the metric for conformance.