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Fan Application
FA/121-23

PRODUCT APPLICATION

A technical bulletin for engineers, contractors and students in the air movement and control industry

The Basics of Fan Sound

Fan sound is a very important consideration in the selection and application of fans. Despite this, fan sound continues to be one of the most misunderstood topics in the air handling industry.

In an effort to provide a better understanding and point of reference on how fan sound is developed, rated, applied, and controlled, this is the second article in a four-part series covering this topic.

Part 1 - *Understanding the Development of Fan Sound Data and the Product Rating Process FA/120-23*

Part 2 - *The Basics of Fan Sound, FA/121-23*

Part 3 - *Radiated Sound, FA/122-23*

Part 4 - *Sound Criteria, Attenuation Techniques and Preventive Measures to Limit Sound Problems, FA/123-23*

This article discusses the nature of sound, sound terminology, different methods of rating fans for sound, and typical calculations that most people take for granted due to online product selection programs.

What is sound?

We are all aware that energy comes in many different forms: light, heat, electrical, nuclear, sound, etc. However, unlike the others, sound is characterized as a form of energy resulting from vibrating matter. As the matter vibrates, it creates waves in the surrounding medium (air, water, metal, etc.) that have alternating compressions and rarefactions. In air, this represents a very small change in the barometric pressure to which our ear drums react. Our ears distinguish one sound from another by its loudness and pitch. Loudness is the amplitude of sound energy reaching our ears. Pitch is the relative quality of the frequency content made up of pure tones as well as broadband sounds. We typically use the pitch to identify the source of a sound. However, both the loudness and pitch may vary depending upon where we are located relative to the sound and the surrounding environment.

What is fan sound?

Fan sound represents a characteristic combination of frequencies made up of many different individual components. It is a byproduct of many different aerodynamic mechanisms going on inside the fan. Some of these include vortex shedding, eddy formations, turbulence, and discrete tones such as the blade frequency. There are also various combinations of mechanical sound coming from drives, motors, bearings, etc. All of these logarithmically combine to form a sound spectrum recognizable to the ear as being a fan noise.

This concept is illustrated in Figure 1. The lower sound spectrum is one-third octave band sound level data from a 24-inch airfoil fan. Note that there are individual peaks that are prevalent at various frequencies. These peaks correspond to the sound contribution of individual components such as the blade frequency, motor, drives, or even a panel resonance from the scroll (fan housing). It is these tones that our ears characterize as fan sound. Please remember, fan sound comes from several sources, aerodynamic as well as mechanical.

By convention, fan sound is presented on an octave band basis in accordance with ANSI standards. This makes dealing with sound less burdensome by using eight numbers versus 24 to define the frequency spectrum. However, when one-third octave band sound values are logarithmically added together into octave bands, the resulting sound level is higher, but the individual peaks are not graphically identifiable in the new spectrum (see top spectrum curve, Figure 1). This does not mean that they are no longer there. Your ear will still hear the tones, but the method of presentation smooths over the appearance of individual component contribution in the data. The octave band data can be further simplified to a one-number system such as LwA or dBA, sones, etc. However, with each simplification in the method of presentation, the identification of specific components is further reduced.

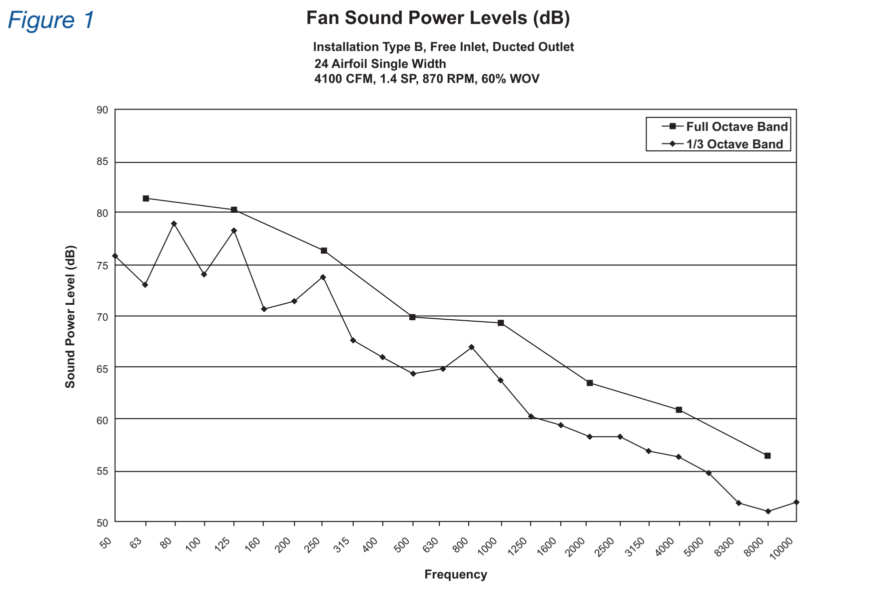

Figure 1

Defining Fan Sound

It is easier to understand fan sound using the graphical format illustrated in Figure 1. Using this figure as a reference, each of the rating parameters will be discussed. It is important to understand the concepts presented since they apply equally well for all fan sound data, not just for this specific example.

Sound Power versus Sound Pressure

The difference between sound power and sound pressure is critical to the understanding of this subject. Most industrial and commercial ducted fan catalog data is presented in sound power levels in each of eight octave bands. However, some commercial and residential non-ducted catalog sound data is presented on a sound pressure basis using a single number rating system such as dBA or sones.

Energy for light, heat, electrical, and most fan sound is provided referenced to the watt. The power produced by a light bulb, a heater, or a fan is an indicator of the power produced at the source independent of the distance from the source or the environment in which it is located. As an example, a 60W light bulb consumes 60 watts no matter where it is located. Fan sound power is the same.

Fan sound power is determined through tests conducted in accordance with ANSI/AMCA Standard 300, "Reverberant Room Method for Sound Testing of Fans." Test results are provided in sound power levels in dB referenced to 10^{-12} watts in each of eight octave bands. This is the sound produced by the fan at its source and is independent of the fan's environment.

Sound pressure levels represent the energy a microphone or our ears would receive and depends upon the distance from the source as well as the acoustical environment of the listener (room size, construction materials, reflecting surfaces, etc.). Sound pressure levels are provided in dB referenced to the microbar (.0002) or 20 micropascals.

Installation Type

Published sound ratings are presented at the fan inlet, fan outlet, or total sound power for the following installation types shown below. It is important to know the installation type that best matches the actual application because sound levels are not the same for each installation.

Installation Type	Configuration
A	Free Inlet, Free Outlet
B	Free Inlet, Ducted Outlet
C	Ducted Inlet, Free Outlet
D	Ducted Inlet, Ducted Outlet

Fan Designation

The size and design of the fan must be identified.

Fan Rating

A manufacturer that participates in the Air Movement and Control Association International, Inc. (AMCA) Certified Ratings Program (CRP) assures the industry that the products and equipment will perform as stated by the manufacturer. Products that are independently third-party tested and performance certified assure the specifying engineer, installing contactor, and facility owner that the products and equipment installed will perform as stated by the manufacturer. The AMCA Certified Ratings Program (CRP) has a label (seal) for "air" and a seal for "air and sound." A sound rating cannot exist by itself. It must have a corresponding aerodynamic rating because sound is a function of the fan design and duty rating point.

Loudness/Amplitude

Because sound loudness is referenced to very small numbers and there also is a very wide range, it is much more convenient to use the decibel (dB). A decibel is a dimensionless number expressing in logarithmic terms the ratio of a quantity to a reference quantity. As an example, one dB represents the threshold of hearing.

Sound Power (dB) =
10 log (sound power [watts]/10^{-12})

Sound Pressure (dB) =
20 log (sound pressure [microbars]/.0002)

Sones

LwA and dBA respectively are sound power and sound pressure rating systems for most industrial and commercial fan equipment. An alternative single number system for loudness description is sones.

Sone acoustic ratings are mostly applied to residential and institutional facilities (i.e., schools, libraries, movie theaters, concert and opera halls, sanctuaries, etc.) Sones follow a linear scale, that is 10 sones are twice as loud as 5 sones. A sone is a term of loudness perceived by the ear related to a frequency of 1,000 Hz. The sone is a sound pressure term at a distance of 5 feet from the fan and is linear to the human ear. The application of sones is outlined in AMCA Publication 302.

The following formula can be used to convert sones to decibels (accuracy +/- 2 dBA):
dBA = 33.2 Log_{10} (sones) + 28

Frequency

Frequency is the number of pressure variations per second expressed in Hertz (Hz). One cycle per second equals one Hertz. The human ear can perceive sound between 20 Hz and 20,000 Hz. However, fan sound is dominant between 50 Hz and 10,000 Hz. Therefore, there is no reason to deal with frequencies outside of this range.

This frequency range for test purposes has been divided into 24 individual bands called one-third octave bands as illustrated in Figure 1. Three one-third octave bands when logarithmically combined form an octave band. An octave band is the interval between any two frequencies having a 2:1 ratio. As an example, the center frequency for the first octave band is 63 Hz. The center frequency for the second octave band is 125 Hz, the third is 250 Hz and so on up to the eighth octave band with a center frequency of 8000 Hz. The abscissa of Figure 1 illustrates the relationship between band numbers and frequency for both one-third and full octave bands.

Perceiving Fan Sound Levels

It is important to maintain a commonsense approach to looking at fan sound. Many people look at sound levels in too strict a manner without maintaining an overall perspective of their significance. From an accuracy standpoint, fan sound levels are less accurate than aerodynamic performance ratings. AMCA 300 indicates that tolerances of +/- 6 dB are possible in the first octave band and +/- 3 dB in the remaining octave bands. When comparing sound levels, a difference of 3 dB is barely perceptible to the human ear. A difference of 5 dB is enough to make a distinction as to which is louder. It takes a difference of 10 dB between two sound levels to make one sound twice as loud as the other.

When looking at sound levels it is very hard to relate that sound level to a typical source, i.e., something we know. Simply to provide some perspective on the loudness of some sounds, the following table contains typical sound categories and corresponding sound levels.

Sound Category	Sound Pressure (dB)
Threshold of Pain	140
Threshold of Discomfort	120
Conversational Speech	60
Threshold of Hearing	0

Typical Sound Calculations

Catalog sound power levels are provided in each of eight octave bands. Sometimes it becomes necessary to take these values and convert them to other conditions. The following sections provide guidance and examples of the most common types of calculations.

Combining Sound Levels

The addition of sound levels must be done on a logarithmic basis, not arithmetic. This addition can be done quickly and easily by computer as well as by hand. It involves a very simple process that is performed repeatedly.

The chart on the next page illustrates the amount two sound levels contribute to each other based upon the difference between them. If two sound levels are identical, the combined sound is 3 dB higher than either. If the difference is 10 dB, the highest sound level completely dominates and there is no contribution by the lower sound level. Examples 1 and 2 on page 5 illustrate combining two sound spectrums into one, and combining an octave band spectrum into a single number, respectively.

Sound Pressure Level Considerations

It has been repeatedly emphasized that sound power level values are independent of the distance and acoustical environment. On the other hand, sound pressure levels are a function of the location of the source as well as the listener. Estimating sound pressure levels requires detailed knowledge of many different parameters. Since fan manufacturers have no idea where their fans or the ultimate listener are located, they are not in a position to calculate sound pressure levels for most applications. However, over the years, in order to provide users with some idea of what sound pressure levels might be expected, a “default set of assumptions” have been made which may or may not match the actual application. This default set of assumptions has been well accepted by users to the point where many catalogs contain sound levels based upon sound pressure. The following sections outline the default assumptions and the calculation process used to obtain various catalog sound pressure levels.

Default Assumptions

The following assumptions are universally used in making sound pressure level predictions.

Point Source

This assumes that the listener is far enough away from the fan to consider it a point source. This is consistent with most theoretical calculations made in acoustics. The key emphasis is that the listener is not in what is called the “near field.”

Directivity Factor

It is assumed that the fan is mounted on a floor, ceiling, or wall. Therefore, it can also be assumed that there is one reflecting surface that bounces the sound waves back toward the listener. This is referred to as a directivity factor of two.

Sound increased based upon the difference between two sounds

dB difference between two levels	0	1	2	3	4	5	6	7	8	9	10
dB added to the higher level	3	2.5	2	2	1.5	1.5	1	1	.5	.5	0

Procedure:

- Select the highest level
- Subtract the next highest level from the highest
- Using the difference, go to the chart and find the addition to the highest level
- Add this to the highest level
- The result is the logarithmic sum of the two levels

Example 1

Combining two sound spectrums

AMCA Band No.	1	2	3	4	5	6	7	8
Spectrum A	82	80	73	70	69	66	60	53
Spectrum B	79	77	71	68	67	64	59	52
Absolute Difference	3	3	2	2	2	2	1	1
Added to Highest	2	2	2	2	2	2	2.5	2.5
Combined Sound Level	84	82	75	72	71	68	62.5	55.5

Example 2

Combining an octave band spectrum into a single number

AMCA Band No.	1	2	3	4	5	6	7	8
Spectrum A	81	80	76	70	69	64	61	57

Note: If more than two numbers are being combined, use the previous sum as the highest number to combine with the next highest number. This is illustrated below.

Procedure:

The highest number is 81, the next highest is 80, the difference is 1, the adder is 2.5, the combined number is 83.5, the next highest number is 76, the difference is 7.5, the adder is .5, the combined sum is 84, the next highest is 70, the difference is 14, the adder is 0. Therefore, the single combined number for this spectrum is 84 dB.

Hemispherical Radiation Pattern

Consistent with the directivity factor, it is assumed that the sound radiates from the fan in a hemispherical radiation pattern. A spherical radiation pattern would mean that the sound radiates equally in all directions from the fan and does not have a reflecting surface.

Straight Line Distance

It is assumed that the sound travels in an uninterrupted straight line from the fan to the listener. In other words, the listener can look directly at the fan and see it. No ductwork is between the fan and the listener. Typically, a distance of five feet is selected as being reasonable.

Free Field Conditions

It is assumed that the sound is free to radiate outwardly in an uninterrupted manner and is not reflected from any other surface other than the floor or ceiling it is mounted upon. The sound is free to radiate to an infinite distance.

Constant Difference Between Sound Power and Sound Pressure

Based upon all of the previous assumptions, (5 feet away from a point source in a hemispherical free field) it is possible to calculate the difference between sound power and sound pressure. This means that the sound pressure level is 11.5 dB lower than the sound power level regardless of octave band.

A Weighting

Sound pressure levels which are heard by the human ear are based upon the "A" scale. There is a constant set of weighting factors illustrated in the following table to approximate the response of the human ear. (Refer to AMCA Publication 303-79.)

"A" weighting factors

AMCA octave band no.	1	2	3	4	5	6	7	8
A" weighting factor	-25	-15	-8	-3	0	+1	+1	-1

It is important to realize that "A" weighting numbers are fully meaningful only when applied to sound pressure values. "A" weighting factors are sometimes applied to sound power levels which are then combined into a single number (LwA). This provides a single number for comparison between fans when sound power spectrums are provided. The LwA number cannot be verified by measurements in the field.

Typical Sound Level Calculations

Several sound level quantities can be calculated using combinations of the previous information. These are illustrated in examples 3, 4, and 5.

Summary

Knowing fan sound values is vitally important. They should be obtained for every fan selection and compared to available acceptance criteria up front in the design stages. This will help provide the assurance necessary for a successful application.

Example 3

Single number sound power level (LwA)

AMCA octave band no.	1	2	3	4	5	6	7	8
Sound power level	75.5	78.5	74.5	74	70	65	61.5	57
"A" weighting	-25	-15	-8	-3	0	+1	+1	-1
LwA by octave band	50.5	63.5	66.5	71	70	66	62.5	56

Combining into a single number (LwA) = 75.5 dB

Example 4

Calculating sound pressure levels

AMCA octave band no.	1	2	3	4	5	6	7	8
Sound power level	75.5	78.5	74.5	74	70	65	61.5	57
Delta power pressure	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Sound pressure level	64	67	63	62.5	58.5	53.5	50	45.5

Example 5

Calculating single number sound pressure level (dBA)

AMCA octave band no.	1	2	3	4	5	6	7	8
Sound power level	75.5	78.5	74.5	74	70	65	61.5	57
Delta power pressure	11.5	11.5	11.5	11.5	11.5	11.5	11.5	11.5
Sound pressure level	64	67	63	62.5	58.5	53.5	50	45.5
"A" weighting	-25	-15	-8	-3	0	+1	+1	-1
"A" weighted pressure	39	52	55	59.5	58.5	54.5	51	44.5

Combining into a single number (dBA) = 64 dB

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