Practical Consideration of Noise from Fans

Charles BURGESS[1]; Rhys THOMPSON[2]

[1] AirEng, Australia

[2] AirEng, Australia

ABSTRACT

Fan noise is often stated based on fan casing breakout alone, ignoring additional noise generation from other fan components, meaning operational and onsite noise levels would be higher than specified. Sources of fan noise are discussed to help identify where problem noise is being produced, and provide suggestion for better specification of attenuation devices. Anti-thrust vanes, inlet and outlet dampers, variable inlet vanes, bearings, belt drives, electric motors and VF drives are commonly neglected when stating the sound performance level of a fan. Noise resonance can also occur from incorrectly designed pedestals, casings and duct work. Noise breakthrough from expansion joints and ductwork with lesser attenuation characteristics than the casing material will increase overall noise. Dust and materials handled by fans also introduces an additional source of noise to be considered. There are suitable options to control the overall noise of the fan as well as focused attenuation for particular fan components and accessories, both will be discussed.

Keywords: Sound, Insulation, Fans I-INCE Classification of Subjects Number(s): 11.4
(See . http://www.inceusa.org/links/Subj%20Class%20-%20Formatted.pdf .)

1. INTRODUCTION

Noise has become a major focus in the design and selection of fans. As availability of space becomes more and more scarce industrial and commercial machinery is increasingly required to meet ever tightening noise restrictions. Fans are a significant contributor to workplace and factory noise levels. This has lead to importance of reliable noise information when fans are specified.

There are three commonly used measurements in the fan industry; free inlet, free outlet and casing breakout. Free inlet is the noise being emitted from the inlet of the fan when there is no duct work attached; likewise free outlet is the measurement at the outlet of the fan with no duct work. The fan casing breakout is the sound emitted through the casing. These figures are generally stated as the A-weighted sound pressure level at one metre – free field propagation. The commonality is useful for fast comparison between competing products.

The measurements given do not take into account many other items that are necessary to operate the fan and other accessories. The common values stated take into account the impeller rotation, air movement and casing thickness only.

The items listed are not generally included in fan noise figures:

- Motor noise
- Changes in motor noise caused by VVVFD/VSD
- Casing design
- Pedestal design
- Dampers or variable inlet vanes
- Ductwork design and thickness
- Bearing noise
- Belt drive noise
- Inlet box design
- Anti-thrust vane noise

[1] Charles@aireng.com.au
[2] Fans@aireng.com.au

- Cooling fin noise
- Shaft hole noise

When fan noise is tested on site it is highly unlikely that the manufacturer's noise data will match exactly to the measured values. This can be for any number of reasons including background noise, reflections and poor installation. Identification of the noise levels from components of the fan and machinery around the fan is the best way to find a solution to any noise issues. Often the mistake of focusing only on the noise emanating from the fan casing leads to a costly solution when much more cost effective methods may have sufficed.

Through design and item specific attenuation devices such as motor mufflers, tunnel bearing housings and shaft seals identified noise problems can be addressed individually. Sometimes there is a need for very low noise emission in residential areas meaning that these devices are not enough to meet requirements, in these cases a full enclosure with acoustic louvers may need to be considered.

2. FAN INDUSTRY COMMON STANDARDS

2.1 Noise Testing

Fan manufacturers also test to various standards like AMCA 300, *Reverberant Room Method for Sound Testing of Fans* (Based on ANSI S12.31, *Precision Methods for the Determination of Sound Power Levels of Broad-Band Noise Sources in Reverberation Rooms*). This standard is a comparison test between a reference source and the fan in an identical location. A different method is to measure the in duct sound power level; AMCA 330-86 *Laboratory Method of Testing In-Duct Sound Power Measurement Procedure for Fans* covers this. The testing is done utilising a test duct with an anechoic termination, measurements are taken in specified locations using an appropriately filtered microphone. These are two common methods of obtaining noise data from a fan only. When testing a fan to produce a noise level it is important to record measurements at multiple points on the fan curve.

2.2 Noise Calculation

Most of the time the noise data provided will be either from interpolation or calculation. It is rare to find any manufacturer with a full set of tested noise values due to the extensive ranges offered.

Calculated figures can be based on flat response curves for typical impeller and fan types.

Table 2.1 – Specific Sound Power at 0.47L/s, 249Pa, dB re 10^{-12} Watts(1)

Fan Type	Centre Frequency - Hz							
	63	125	250	500	1000	2000	4000	8000
Centrifugal Airfoil	35	35	34	32	31	24	18	10
Centrifugal Backward Curved	35	35	34	32	31	24	18	10
Centrifugal Radial	48	45	43	43	38	33	30	29
Centrifugal Forward Curve	40	38	38	34	28	24	21	15
Vane Axial	42	39	41	42	40	37	35	25
Tube Axial	44	42	46	44	42	40	37	30
Propeller Axial	51	48	49	47	45	45	43	31
Tubular Centrifugal	46	43	43	38	37	32	28	25

These figures are then adjusted based on the type of fan, flow rate (Q), pressure (P_{total}), rotational speed, number of blades and fan efficiency (K_{eff}) to arrive at an approximate noise level.

$$LW(dB) = SpecificNoise + BPF_{correction} + 20\log_{10}\left(\frac{P_{total}}{249}\right) + 10\log_{10}(Q \times 2.13) + K_{eff} \qquad (1)$$

This is a simple method helpful in determining a conservative estimate of noise power output from the most common types of fans.

Interpolation from tested data is described in AMCA 301 *Methods for Calculating Fan Sound Ratings from Laboratory Test Data*. Using this method calculation of noise levels for fans that are proportionally similar can be done. The calculated noise values only match points direct related, via fan laws, to the measured data.

3. IDENTIFICATION OF NOISE FROM SOURCES

3.1 Fan

The fan is the dominant source of noise from most complete units. Depending on the type of fan it can have many different characteristics. As seen in table 2.1 the specific sound power for each type of fan varies across the spectrum for a given flow rate. When analysing multiple sources to identify problem areas the table is helpful in comparing measurements to the expected fan characteristics.

Backward inclined centrifugal fans have the lowest specific noise output whether they be airfoil, curved or flat. Their characteristic noise is in the lower frequencies with a reasonable drop off in noise power generation in the higher octaves.

Radial centrifugal fans are one of the worst performing in comparison. Their noise characteristic is high low to mid range octave values with a, relatively, lower values in the high octaves.

Tubular and forward curved centrifugal fans have similar characteristics to backward centrifugal types but as they are less efficient they have a higher specific sound power output across all octaves.

Axial fans are the worst performing fan type along with propellers they produce high specific noise levels across the whole spectrum.

All of these fan types are subject to blade passing frequency (BPF) noise generation. Identification of the expected BPF is easily achieved as it will always be generated at a fixed frequency that is based on the number of blades a fan has and the rotational speed.

$$BPF = \frac{No.Blades \times RPM}{60} \tag{2}$$

Poorly designed casings and pedestals will also add to the noise emission from the fan. Casings that are not sufficiently stiffened or with section sizes that reverberate with the noise generated by the impeller and air movement add to the problems in identifying sources. Vibration testing of the casing will help to identify the frequency of vibration and allow determination if it is a contributory factor in the overall package noise. Similarly, the fan pedestal, if poorly designed, can have a similar effect. Reverberation of the noise that has passed through the casing or vibration and noise emitted from the motor can occur when noise design considerations are not included in the stiffening of the pedestal.

3.2 Motor

Although the motor is an inseparable part of the fan the noise output that it produces is very rarely taken into account during fan selection and design. Motor manufacturers provide noise data for all models, generally as a single overall value as per AS 60034.9 in sound pressure level at one metre, most values will be for the motor at no load. Dependant on the size of the motor, the SPL from the motor alone can be above 85dB(A). Considering this in conjunction with a fan that has been designed for the same noise level would result in the package being above the required limit by 3dB.

Motors have a fairly flat un-weighted noise characteristic. With the majority of the sound level being produced by air movement through the cooling fan for high speed motors (2 and 4 Pole) and magnetic noise being the driving factor for lower speeds (6 and 8 Pole and above). This is shown by measurement under no load and under load, where noise will decrease slightly on high speed motors under load and increase slightly on low speed motors.

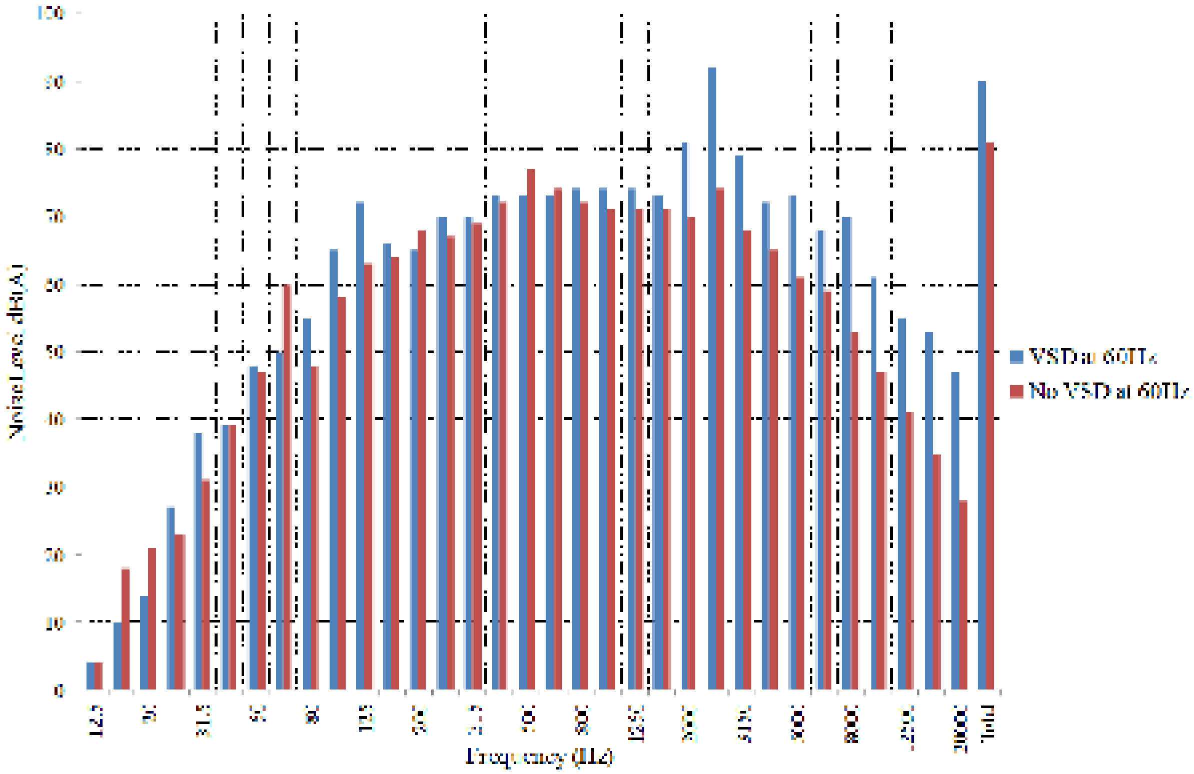
3.3 VSD/VVVFD

Variable voltage variable frequency drives, or variable speed drives, aren't always part of a unit package but increasing demand for efficiency is leading to adoption on more packages. VVVFD/VSD's may not produce much noise while in operation but they do change the noise produced by the motor. While operating via a VVVFD/VSD the characteristic noise and level of output of a motor will be altered. The lower frequencies will drop slightly while there will be a large increase in the higher frequency ranges and a small increase across the middle range. The overall noise increase from operation via VVVFD/VSD will vary depending on the size of the motor and other factors. Increases of 3-8dB are typical values but can range up to 11dB in some circumstances. Table 3.1 shows the influence inverters can have on motors at different switching frequencies when compared to no inverter present. Even on small motors the noise increase caused by inverters is large. VVVFD use often produces a large spike in a particular frequency range as can be seen in chart 3.1 between 2000 and 3150Hz.

Table 3.1 – Influence of Inverter on the Sound Pressure Level of Motors in dB (2)

Motor Power (kW)	No. Poles	Grid Connected (60Hz)	Switching Frequency of Inverter								
			3.6 kHz			7.2kHz			14.4 kHz		
			30Hz	60Hz	100Hz	30Hz	60Hz	100Hz	30Hz	60Hz	100Hz
0.37	4	46.1	52.1	50.5	58.9	42.2	49.3	58.9	37.1	46.8	58.8
0.75	2	61.2	41.2	68.2	73.1	45.9	60.5	72.7	44.7	60.4	72.8
0.75	4	44.7	60.3	52.9	58.8	47.0	57.1	59.5	34.4	46.8	58.5
2.2	2	67.5	60.6	68.5	80.8	54.9	68.4	80.8	53.3	68.2	81.1
2.2	4	53.1	68.7	60.6	63.8	56.6	65.4	64.7	46.6	52.9	63.4
4	4	54.4	56.3	58.7	66.8	53.7	65.6	67.0	44.3	54.8	66.5
5.5	4	56.3	61.8	59.6	68.1	52.9	63.6	68.2	43.0	56.5	58.0
7.5	4	61.7	65.1	71.1	73.7	57.2	68.1	73.4	46.7	61.9	73.4
15	4	69.2	68.7	73.4	80.9	54.8	69.8	80.8	52.5	69.3	80.7

Chart 3.1 – Effect of VVVFD on a 630kW 2P Motor Running at 60Hz



3.4 Bearings

Bearings aren't considered a noise source on fans due to their relative low noise output. Rolling element bearings when in normal operation will not produce noise much above a whisper even for the larger sizes. Sound Pressure Level output of large bearings has been measured at 52dBA(3). Smaller bearings are barely audible. Only in ultra low noise level applications would the noise from bearings require consideration. Higher noise levels are much more common in high speed applications rather than high load.

3.5 Shaft Seal

For centrifugal fans the point in the casing that the shaft passes through can be a major source of noise. While the primary consideration when fitting a shaft seal is to maintain flow and pressure within the fan but the biggest benefit is often the reduction in noise through the gap. As the gap area is a direct outlet from the casing without any attenuation it can emit a noise level similar to that of a free inlet or free outlet if not sealed properly. While the noise emitted does not have any unique characteristics that will allow isolation from the casing breakout; testing in multiple positions equidistance from the fan casing will quickly highlight any excess noise in the region.

3.6 Flow Control Devices - Dampers and VIV's

Like any object in an air stream damper blades and variable inlet vanes for flow control devices will produce disturbance and create noise. The level of noise will depend on the angle the flow control device is closed to. Measured figures show that the worst position of an inlet flow control device can add 6dB to the overall sound power within the duct and fan casing. The noise generation is relative to the pressure drop created by the damper. See table 3.2 for an example spectrum with a damper fully closed and in a semi open position for a medium sized fan.

3.7 Inlet Boxes

An inlet box creates a large flat surface directly in front of the inlet. This can cause higher than expected noise breakout through the material of the inlet box as most of the sound pressure being emitted from the inlet is directed at the front side of the inlet box. Similarly with the casing this can cause reverberation and drumming as well. Design of the inlet box should take into account the different situational effects when compared to the design of the casing.

3.8 Anti Thrust Vanes and Cooling Fins

Can be similar to a radial impeller situated on the backside of a centrifugal impeller these will add to the overall noise of the fan. Anti thrust vanes are found on larger high duty fans where the load of the air entering the inlet causes thrust loads in excess of bearing limits.

Table 3.2 – Effects of Accessories on Fan Noise Output

Configuration	Octave Band Centre Frequency in Hz							
	63	125	250	500	1000	2000	4000	8000
Standard	56	76	93	92	95	96	91	86
Anti Thrust Vanes	56	76	96	94	95	96	92	87
Fully Closed Damper	53	78	97	96	98	100	96	91
35% Closed Damper	56	79	98	97	100	101	96	90

Cooling fins for high temperature fans are another basic radial impeller with no shroud. As with anti thrust vanes they will contribute a small amount to the overall noise of the unit package.

3.9 Duct Design and Components

Focusing on the fan design is only part of the equation when measuring noise levels in situ. Duct work connected to the fan must also be considered when identifying areas that require attenuation. One of the main problems for ducted fans is a discontinuity of material thickness from the fan casing to the duct work see table 3.3 for attenuation difference example. It is important that the thickness of the ductwork being connected to the fan be advised if an overall unit package noise limit needs to be met. The level of breakout noise through duct work can be easily isolated by measuring at increasing distances from the fan unit along the duct.

Table 3.3 – Transmission Losses for Field Incidence in dB (4)

Material	Thickness	Octave Band Centre Frequency in Hz							
	(mm)	63	125	250	500	1000	2000	4000	8000
Aluminium	6	14	20	26	29	29	29	30	40
Concrete	100	15	21	27	33	38	38	38	48
Concrete	200	21	27	33	38	38	38	48	58
Glass	6	13	19	25	27	27	27	30	40
Lead	1.5	14	20	26	32	38	44	50	56
Plastic	25	22	28	30	30	30	36	46	56
Plywood	6	0	6	12	18	19	19	20	30
Steel	3	15	21	27	33	39	40	40	40
Steel	4	20	26	31	37	40	40	40	40
Steel	6	23	29	35	40	40	40	40	47
Steel	12	29	35	40	40	40	40	47	57
Steel	25	34	40	40	40	40	45	55	65

Bends and duct ends can be considered in the same ways as inlet boxes. Abrupt changes in direction will increase the amount of sound pressure on one particular surface of the ductwork, this is particularly important if there are duct bends in close proximity to the fan outlet or inlet.

Flexible connections to ductwork will help to reduce some noise and vibration being transferred through the duct. These connections must have their acoustic properties considered as well. Similar to thin ductwork some basic expansion joints will not match the attenuation of the fan casing.

Duct shape is also an important factor to consider. Circular duct is highly effective at reducing noise breakout with transmission loss figures in the range of 50dB at 63Hz octave band down to 30dB at 8kHz octave band, when compared to square or rectangular duct of a comparable size which showed transmission loss from 15dB at the 63Hz octave band to 40dB at the 8kHz octave band (5). Because of the energy lost in transmission the attenuation per metre along a square duct will be lower than that of a round duct; with the square duct at 0.3dB per metre and the circular duct at 0.12dB per metre for comparable sizes (4).

3.10 Belts

V-Belts do not produce a large amount of noise, similar to bearings they are quiet, below 65dB(A), as long as they are used properly. Misalignment, worn belts, worn pulleys and incorrect belts can increase noise generation severely with noise being produced by the rubbing, vibration and slipping of the belts. As the noise is generated by improper use repair is more common than attenuation for noise. Timing belts produce much higher noise levels where 80-100dB is not uncommon in high speed applications.

4. SOLUTIONS FOR SPECIFIC NOISE ISSUES

4.1 Fan Casings

There are two favoured ways of reducing the noise produced within the fan casing. These methods will attenuate noise caused by the impeller, anti-thrust vanes and flow control devices. The same methods can be applied to inlet boxes to reduce breakthrough noise.

Heavy gauge material: As shown in table 3.3 thicker materials will provide higher transmission loss. This can be a cheap and effective way of achieving reduction below the required limit however the attenuation benefit diminishes quickly after 12mm thickness, in mild steel, and the cost to benefit ratio becomes intangible. Dependant on frequency range higher gauge material may provide the attenuation required with thicker materials continuing to improve attenuation at lower frequencies. When the required limit cannot be achieved with increases in material thickness alone lagging and cladding can be utilised to insulate the fan case.

Lagging and cladding: can be used for fan casings as well as inlet boxes and duct work. Comprised of an insulating material and a method of fixing the material to the structure, an external light gauge metal case in some cases (cladding), lagging and cladding is the next step if the breakout noise is still too high through heavy gauge casing. Lagging and cladding does have its limitations; space and cost restrictions may mean that other methods may need to be undertaken to reach the required noise limit.

4.2 Inlet and Outlet

In various scenarios silencers are the required to attenuate the noise to an acceptable level at the inlet or outlet of the fan. Sometimes silencers are only considered for free inlet or free outlet conditions where there is no duct work to attenuate the noise. In cases where modification to duct work is prohibitively expensive, duct thickness is not sufficient or where duct design limitations leave areas that could reflect or transmit higher levels a silencer can be considered as a cheaper option to reduce the noise level that enters the duct.

4.3 Drive components

Acoustic guards are the best way to deal with noise from drive line components such as bearings and belts. As discussed it is unlikely that anything more than a standard guard will be required to attenuate out noise for anything other than a silent fan requirement.

4.4 Motor Mufflers

Targeting noise created by motors either on mains supply or when their noise is increased by the use of a VVVFD can be achieved with use of a motor muffler. Motor mufflers are most commonly a multi piece silencer. One piece is shaped to cover the motor itself excluding the area where the motor sits on the pedestal to help attenuate the magnetic noise produced. A second piece, a short circular silencer, is attached to the motor cover at the motor fan end to attenuate noise generated by the air flow and fan operation. This is a quick way to correct some noise issues as the motor is the second largest contributor to noise in the fan package. Muffling the motor will help to remove its contribution to the overall noise emission and bring the level of the package much closer to original data that may have been provided based solely on noise sources within the fan case alone.

4.5 Shaft Sealing

Noise leakage, from inside the casing, around the shaft can be controlled by a shaft seal. There are a few types of shaft seal with different seals offering varying levels of seal. For most applications a standard copper plate shaft seal, that consists of a flat piece of copper with a tight tolerance shaft hole, will suffice and stop enough leakage. In more crucial applications a split seal may be a better alternative. Split seals can be single or multiple element; they have a split housing which bolts to the fan case, usually machined from steel, and a split element held in place by a spring wrapped around an outside groove. The element can be made of various materials. Split seals are very effective at sealing the casing from the atmosphere and are recommended in all applications, budget willing.

4.6 Full Fan Package

When single component attenuation, or any combination of them, is not enough to lower the noise output of the fan package including all accessories to the required noise limit, or they become cost prohibitive, a noise enclosure can be considered. Designed with adequate ventilation and acoustically designed intake and exhaust areas enclosures are a good way to isolate the noise of the whole fan package if space and budget allows.

5. CONCLUSIONS

Understanding what noise data you are being provided with is the first step in understanding what requirements are likely to be met and what options are going to be required to meet the noise limitations on site. Factors varying from neglected equipment to site installation conditions can greatly change the measured noise when in operation on site.

It is always best to have as much information about the application available during the design stage when there is a maximum limit imposed on such a critical, and sometimes, costly problem. The minimum recommended information at initial design is; Overall noise limit, Site layout (showing nearby reflective items), Duct work properties (if ducted), VVVFD utilisation and Required accessories. This is by no means all the information that could be provided. This is the recommendation as a guide to lower possible down time and costly modifications on site due to measured noise levels exceeding the imposed limitations.

For currently existing fan packages with noise problems it is best to analyse the retrofitting needs on a case to case basis. While attaching every attenuation device will work it may not be the most cost effective method. Clearly identifying the noise levels and the required attenuation is highly recommended to find the most cost effective attenuation device(s). There is no benefit to retrofitting lagging and cladding to a fan if all that was required to achieve the target noise level was a better shaft seal arrangement.

Analysing each component of a fan package during design is an important practice, whether the contribution to total sound pressure be as small as a belt or bearing or as large as a motor or fan rotating assembly attenuation of the noise generated by any component may be enough to achieve the reduction you require.

ACKNOWLEDGEMENTS

REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers. *ASHREA* Handbook. Atlanta, GA: ;2009
2. Sebastiao Lauro Nau & Hugo Gustavo Gomez Mello. *Acoustic noise in induction motors: causes and solutions*. : ; 2000.
3. Tatsunobu Momono & Banda Noda. *Sound and Vibration in Rolling bearings*. Basic Technology Research and Development Center: ; 1999.
4. Robert Jorgensen. *Fan Engineering,* 8 ed. Buffalo, New York: Buffalo Forge Company; 1983
5. A Cummings. *Sound Transmission Through Duct Walls*. School of Engineering, University of Hull. Report number: 1, 2001.