

Fan Sound

Franco Cincotti, COMEFRI-USA

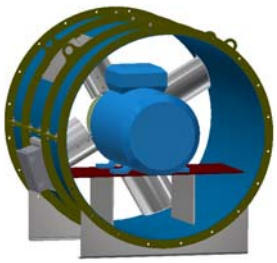
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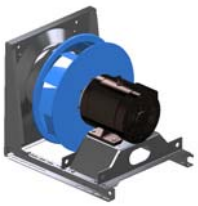
Learning Objectives

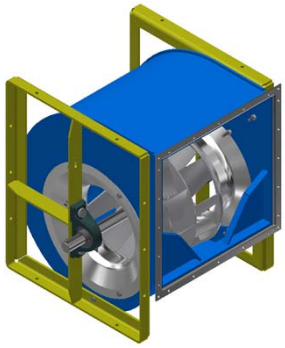
- Sound generation mechanism and sound characteristics
- Fan sound test methods and fan sound prediction
- Sound of different fan types
- Fan installation best practices and common mistakes
- Fan Sound transmission and sound criteria

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Fan as source of Sound





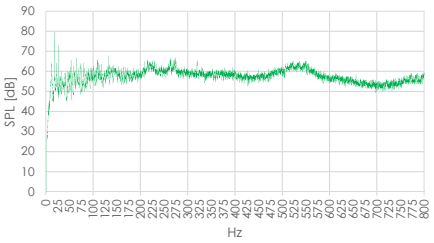


In the process of producing airflow and generating pressure to overcome the system resistances, the fans also generate Sound, more specifically Aerodynamic Sound.

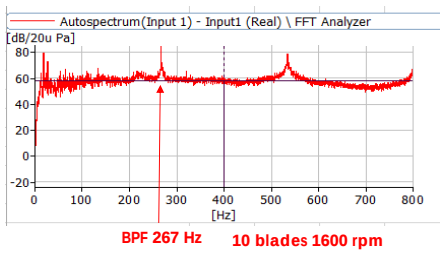
Fan Sound Power is the Rate at which Sound Energy is generated by the fan and transmitted thru the fan inlet, the fan outlet and the fan casing.

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Mechanism of Aerodynamic Sound Generation



Randomly fluctuating aerodynamic forces between the fluid, the fan blades and stationary components generate **Broad Band Sound**. Turbulent airflow, boundary layer, vortexes, flow separation, wake shedding.



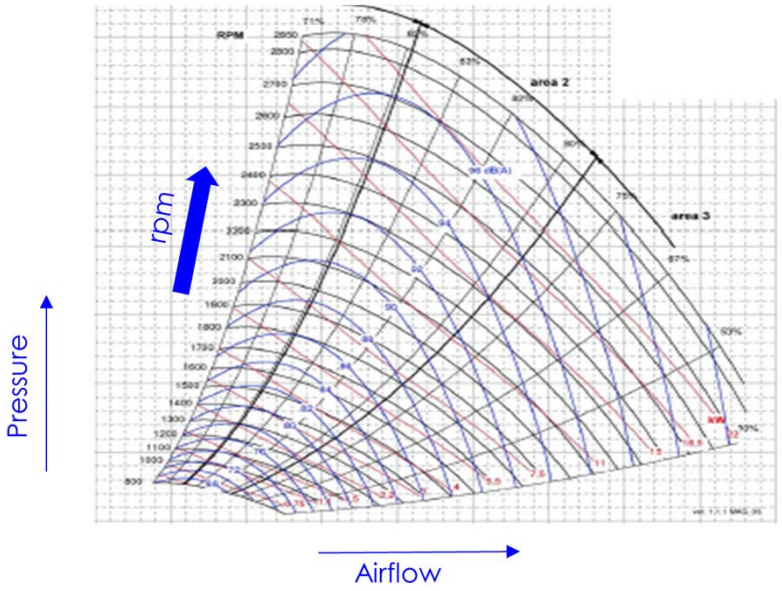
Periodic fluctuating aerodynamic forces between the fluid, the blades and stationary components generate **Discrete Frequency Sound (Tonal Sound)**. Non-uniform inlet conditions, stationary obstacles at the impeller inlet or outlet.

BPF [Hz] = B x rpm /60

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Fan Sound variations with working conditions

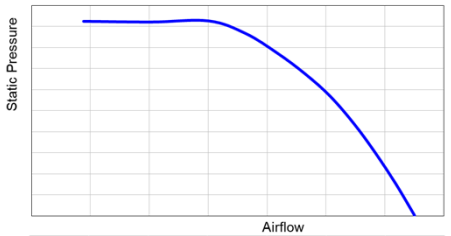
Fan Sound increases with increased fan speed, increased airflow and pressure generated.

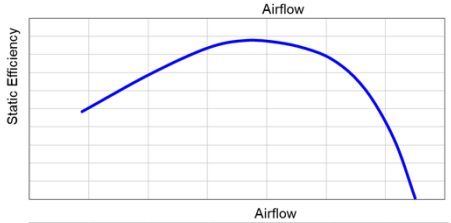


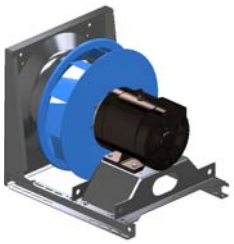
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Fan Sound variations with working conditions

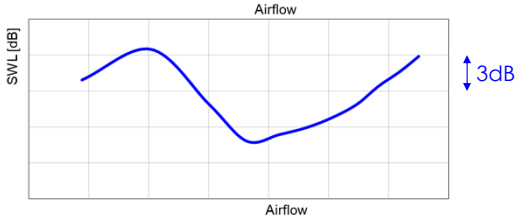
Fans operating close to peak efficiency, minimize the turbulences, flow separation and the Sound that the fan generates.







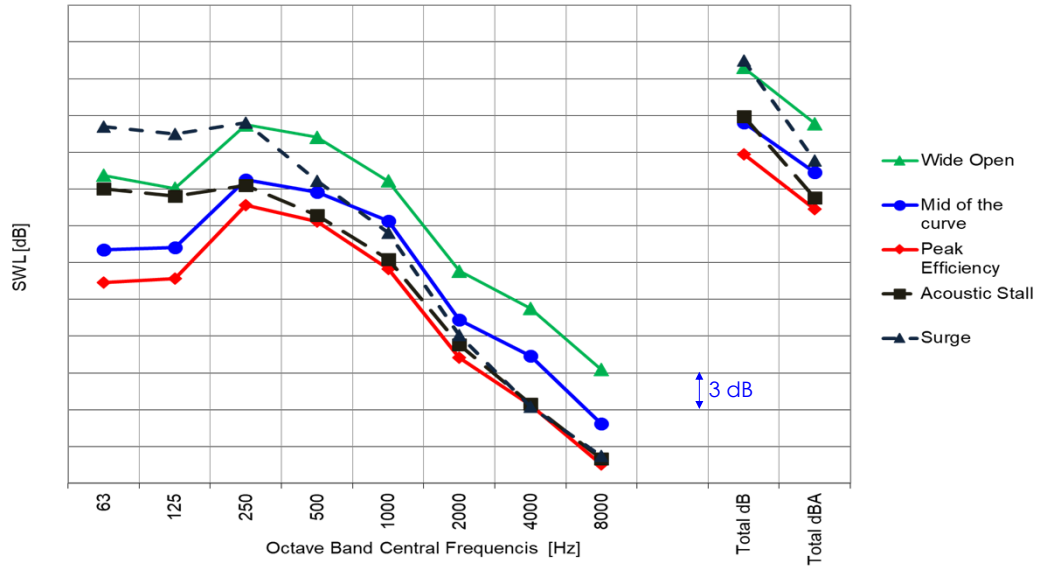
Moving away from the fan peak efficiency, the fans generate more Sound.



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Fan Sound and Frequencies

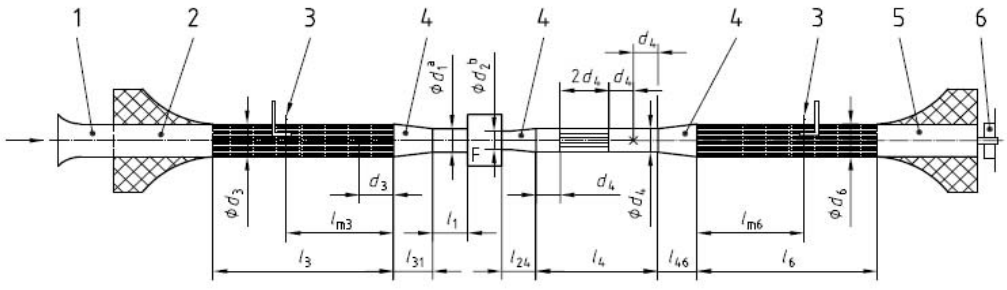
Sound generation, transmission, attenuation, **sound effects and perception in the receiver** *(sensitivity and annoyance) are related to the sound distribution across the frequencies.*



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Fan Sound Measurement

Test Data are the preferred source of Fan Sound Power Levels



Key

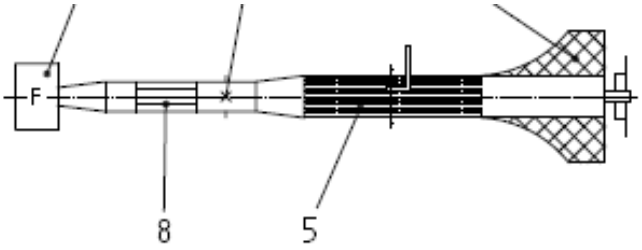
1 flow measurement (schematic)
2 anechoic termination (schematic)
3 measurement plane
4 conical or rectangular-to-round transition
5 anechoic termination (schematic)
6 throttle (schematic)

In-duct method

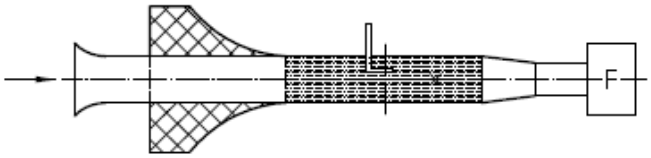
Lw = Lp + 10xLog(S) + C

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Fan Sound Measurement



b) Installation category B



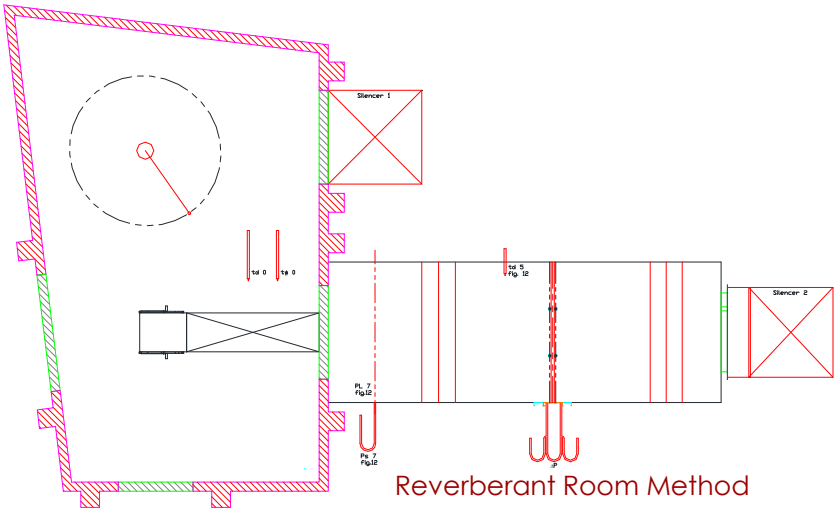
c) Installation category C

In-duct method

$Lw = Lp + 10xLog(S) + C$

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Fan Sound Measurement



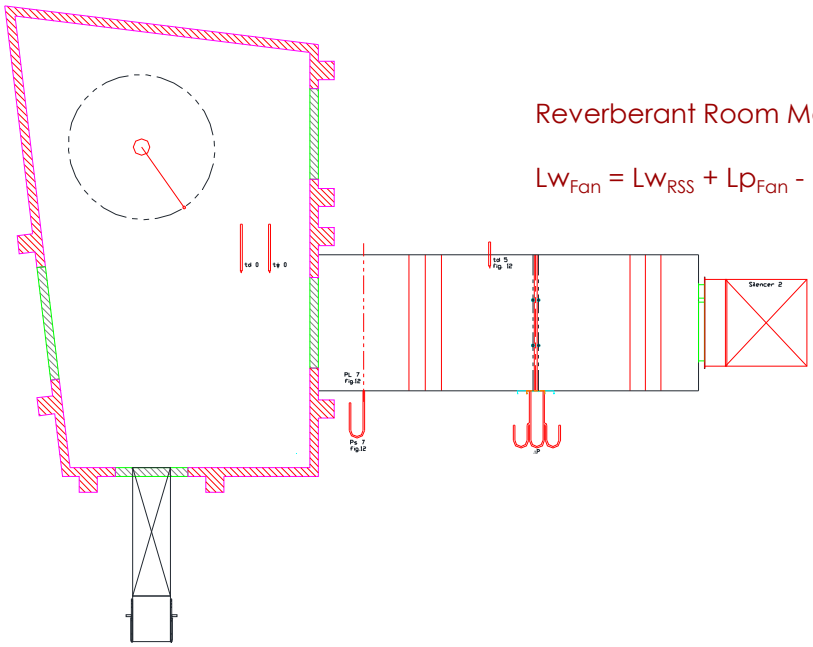
Reverberant Room Method

$Lw_f = Lp_f + 10xLog(V) - 10xLog(T_f) - 14dB$

$Lw_{Fan} = Lw_{RSS} + Lp_{Fan} - Lp_{RSS}$

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Fan Sound Measurement

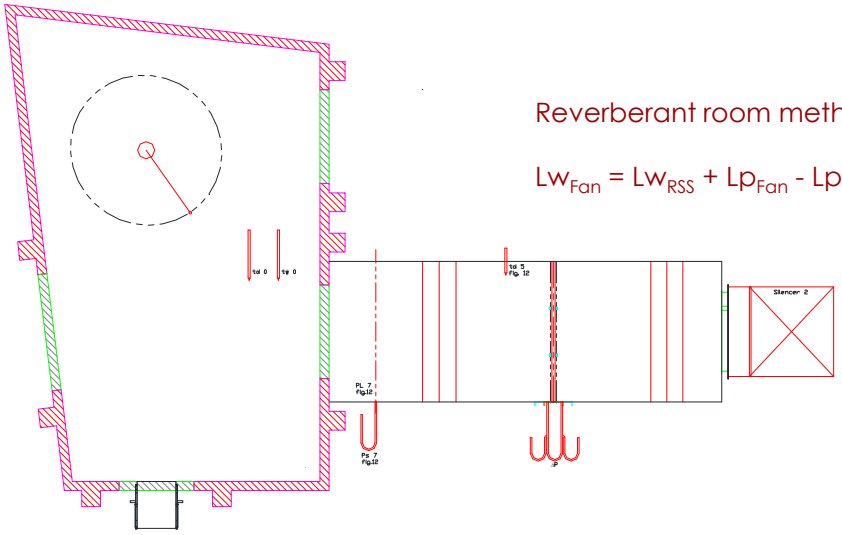


Reverberant Room Method

$Lw_{Fan} = Lw_{RSS} + Lp_{Fan} - Lp_{RSS}$

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Fan Sound Measurement



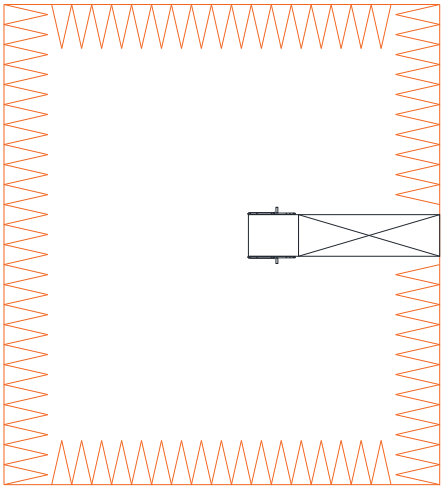
Reverberant room method

$Lw_{Fan} = Lw_{RSS} + Lp_{Fan} - Lp_{RSS}$

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Fan Sound Measurement



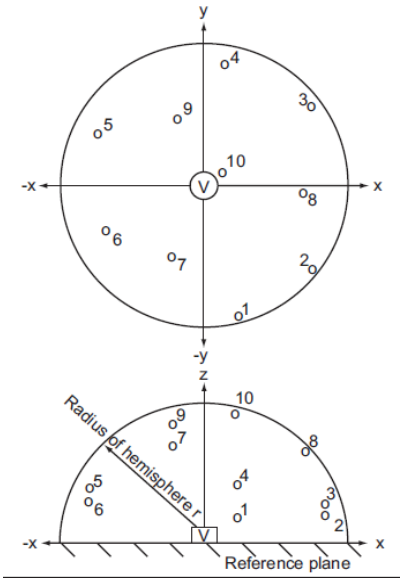


Free Field testing - Anechoic Chamber

$Lw = \overline{Lp} + 10xLog(S)$

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Fan Sound Measurement



Enveloping Surface Method

$Lw = \overline{Lp} + 10xLog(S) - K$

$K = \overline{Lp}_{RSS} + 10xLog(S) - Lw_{RSS}$

Sound Intensity Method

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Prediction of Fan Sound

Dimensional Analysis for geometrically similar fans indicates:

$$SW = K \times Pw \times Ma^{(x)} \times Re^{(y)}$$

$Pw = K' \times N^3 \times D^5$

$Ma = K'' \times N \times D$

$Re = K''' \times N \times D^2$

$$SW = K \times N^{(3+x+y)} \times D^{(5+x+2y)}$$

$$Lw = K + 56 \times Log(N) + 72 \times Log(D) \quad (x=3 \quad y= -0.4)$$

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Prediction of Fan Sound And Acoustic Similarity Laws

Beranek Total sound with tabled spectra corrections

$Lw = 40 + 10 \times Log(Q) + 20 \times Log(P)$

$Lw = 67 + 10 \times Log(kW) + 10 \times Log(P)$

$Lw = 94 + 20 \times Log(kW) - 10 \times Log(Q)$

Dimensional analysis it is not satisfied, results are consistent with measurements in many series of fans.

Points that are in aerodynamic similarity:

$$Lw_2 = Lw_1 + 10 \times Log(Q_2/Q_1) + 20 \times Log(P_2/P_1)$$

$$Lw_2 = Lw_1 + 50 \times Log(N_2/N_1) + 70 \times Log(D_2/D_1)$$

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Prediction of Fan Sound And Acoustic Similarity Laws

$SW = KxQxP^{(a)}$

$Lw = K + 10xLog(Q) + 10x(a)xLog(P)$

a = 2 $Lw = 36 + 10xLog(Q) + 20xlog(P)$

$Lw_2 = Lw_1 + 50xLog(N_2/N_1) + 70xlog(D_2/D_1)$ (centrifugal)

a = 2.25 $Lw = 30 + 10xLog(Q) + 22.5xlog(P)$

$Lw_2 = Lw_1 + 55xLog(N_2/N_1) + 75xlog(D_2/D_1)$ (axial)

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Prediction of Fan Sound And Acoustic Similarity Laws

$Lw_2 = Lw_1 + 60Log(N_2/N_1) + 80xlog(D_2/D_1)$

$Lw_2 = Lw_1 + 10(6+a)Log(N_2/N_1) + 10(8+2a+b)xLog(D_2/D_1)$

AMCA 301:

$Lw_2(f_2) = Lw_1(f_1) + 50xLog(N_2/N_1) + 70xLog(D_2/D_1)$

$f_2 = f_1x(N_2/N_1)$

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Prediction of Fan Sound

$Lw(f) = Kw(f) + 10xLog(Q) + 20xLog(P)$

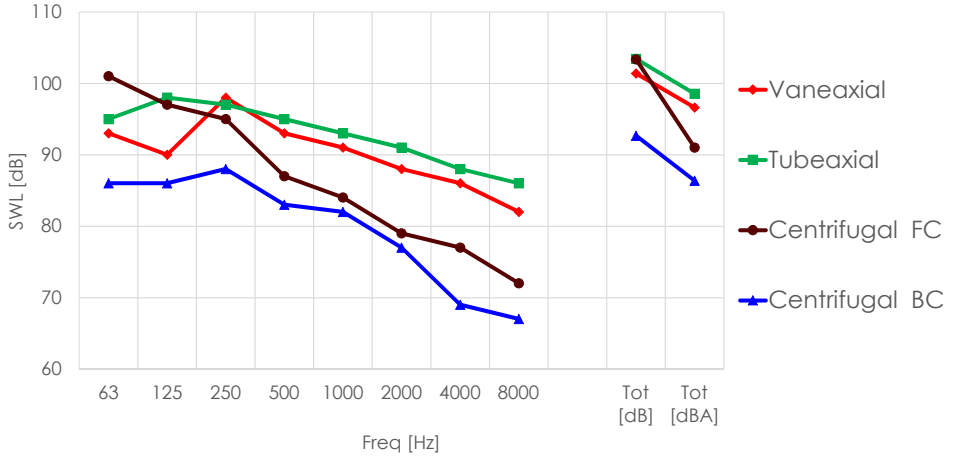
$Lw(f) = Kw(f) + 10xLog(Q) + 20xLog(P) + 40 + BFI + C$

		63	125	250	500	1000	2000	4000	8000	BFI
Centrifugal BC	D > 0.9	-23	-23	-24	-26	-27	-32	-40	-42	3
	D < 0.9	-17	-17	-19	-21	-22	-27	-35	-40	3
Centrifugal Radial	All	-10	-16	-13	-16	-18	-23	-25	-28	8
Pressure Blower	D 0.5 to 1	0	-7	-7	-10	10	-15	-17	-20	8
	D < 0.5	8	2	-3	-5	-11	-16	-19	-22	8
Centrifugal FC	All	-8	-12	-14	-22	-27	-30	-32	-37	2
Vaneaxial	D > 1	-16	-19	-17	-16	-18	-21	-23	-27	6
	D < 1	-18	-16	-12	-12	-12	-14	-17	-19	6
Tubeaxial	D > 1	-14	-16	-12	-14	-16	-18	-21	-23	5
	D < 1	-15	-14	-8	-9	-11	-12	-18	-21	5
Propeller (cooling towers)	All	-7	-4	-3	1	0	-3	-9	-13	5

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Prediction of Fan Sound

$Lw(f) = Kw(f) + 10xLog(Q) + 20xLog(P) + 40 + BFI + C$

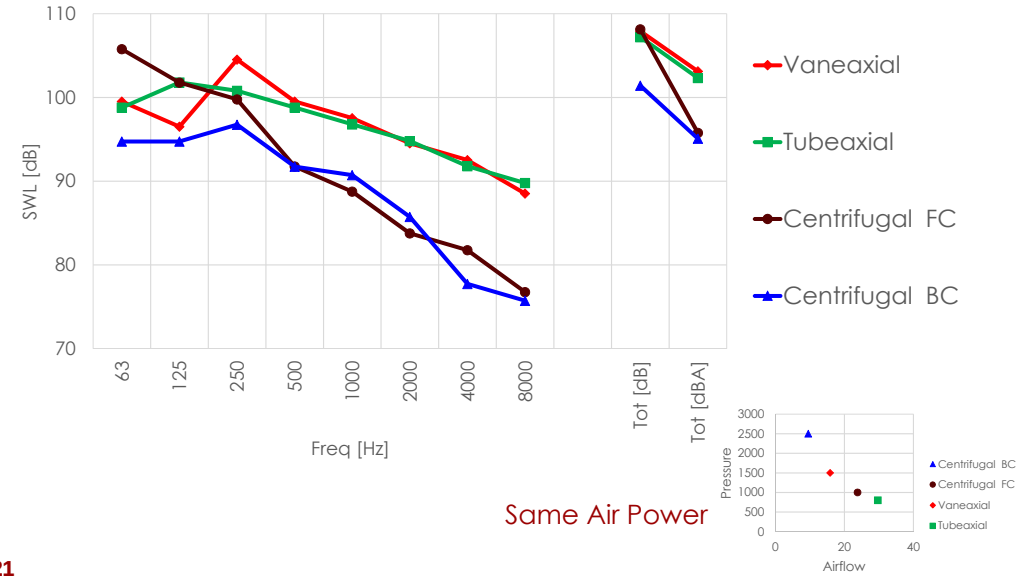


Same Working Point

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Prediction of Fan Sound

Lw(f)= Kw(f) + 10xLog(Q) + 20xLog(P) + 40 + BFI + C

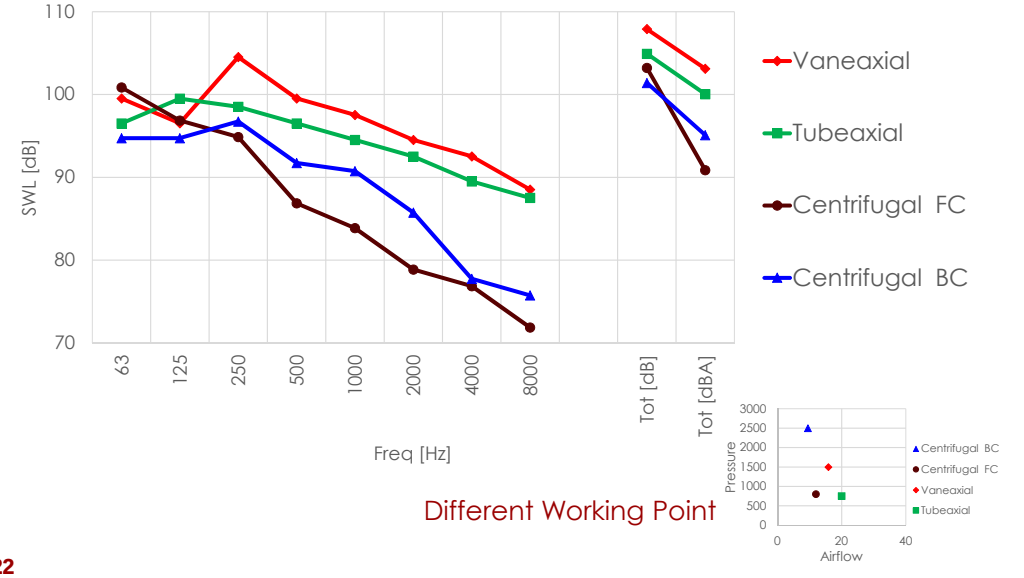


Same Air Power

21

Prediction of Fan Sound

Lw(f)= Kw(f) + 10xLog(Q) + 20xLog(P) + 40 + BFI + C



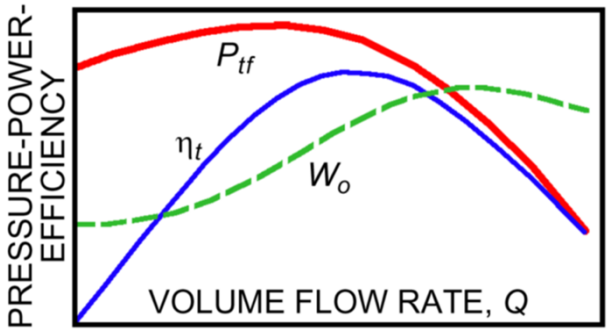
Different Working Point

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Backward Curved Fans

- Medium and high pressure – Highest aerodynamic efficiency
- Lowest operating noise level
- Left of the peak efficiency low frequency noises can rise 10 – 15 dB



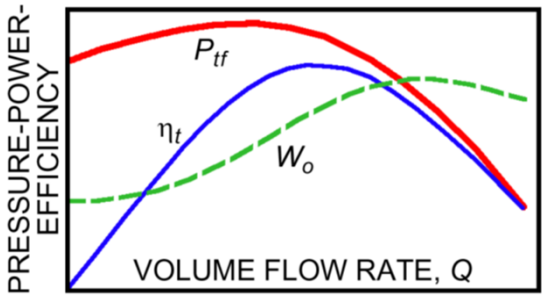


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Backward Curved Fans

- Distance tip of the blades - cutoff is critical for Sound Tonal components; values of 10% to 12% of D are recommended
- Cut-off at an angle with the tip blades can reduces the Tonal components
- Increased number of blades can reduce the Tonal Noise but may increase the broad band noise
- Staggered blades in DWDI fans reduce the BPF noise



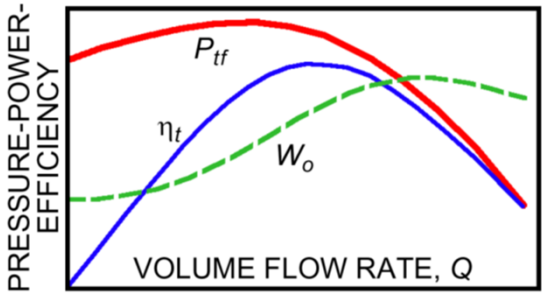


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Backward Curved Fans

- Uneven spacing of the blades reduces tonal amplitude at BPF but increases amplitude of other frequencies
- Minimum clearance between inlet cone and impeller shroud improves efficiency and reduce sound level
- Inlet disturbances contribute to Tonal Noises.
- Side wall spacing of 0.5D to 0.25D produce increase in sound levels of 4 to 8 dB

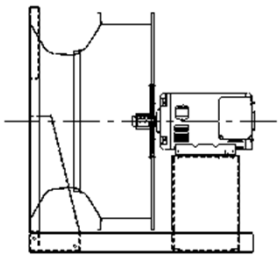


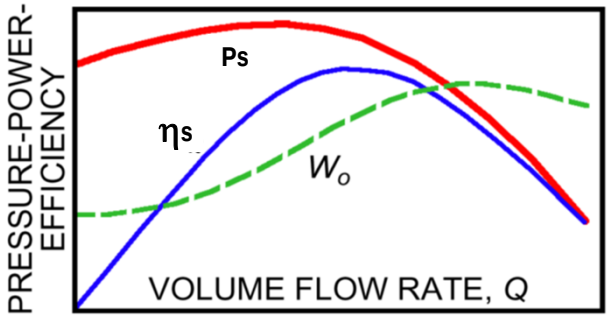


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Backward Curved Plenum Fans

- Medium and high pressure – Lower efficiency than housed BC Fans
- Lowest outlet sound operating noise if the plenum space is properly sized and treated with sound absorbing material
- Blow through installation acoustically preferred to draw through installation
- Left of the peak eff. the low freq. noise can rise 10 dB

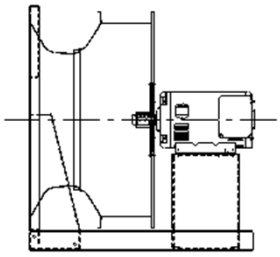


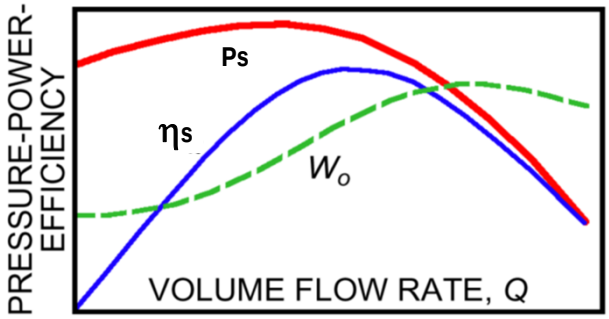


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Backward Curved Plenum Fans

- Sound levels and Tonal components in plenum fans are very sensitive to side flow intake . These non-uniform inlet conditions increase the Sound levels of 4 to 8 dB. The installation of 45° inlet baffle can mitigate the effect

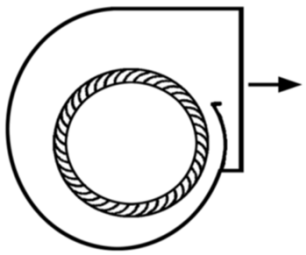


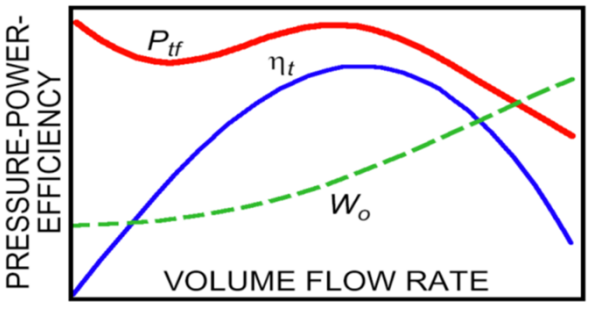


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Forward Curved Fans

- Low pressure range – Low Efficiency
- Subject to stall and surge (left of the peak) with rumble (low frequency noise) and tonal component at 2/3 rpm/60 when in stall
- Best suited for constant volume systems rather then variable air volume applications

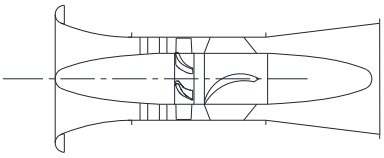


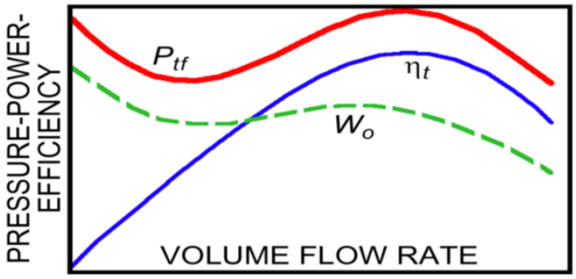


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Vane-Axial Fans

- Medium and high pressure – High aerodynamic efficiency
- Lowest "low frequency" noise; high "medium-high frequency" noise often requiring sound attenuators
- Very acoustically sensitive to inlet flow obstructions (tonal noise)
- Pronounced peak of sound at BPF that with poor inlet conditions can rise 10 dB
- High instability at the left of the peak pressure

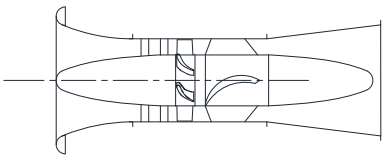


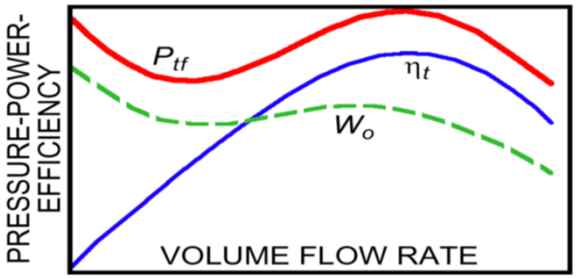


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Vane-Axial Fans

- To minimize Tonal Noise the inlet obstacles, structures, bends should be at 3-4 D
- Inlet guide vanes should be avoided
- Outlet obstacles should be far from blades trailing edge
- Outlet guide vanes should be kept at 1 chord from the impeller trailing edge
- Uneven spacing of the blades reduces tonal amplitude at BPF but increases amplitude of other frequencies

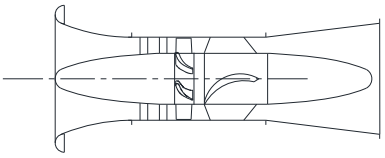


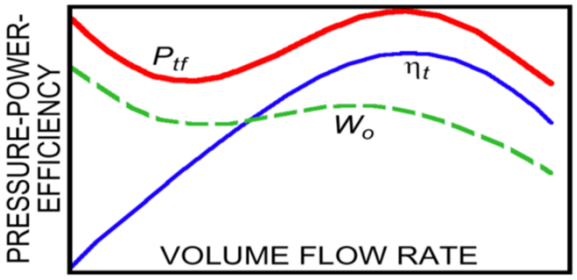


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Vane-Axial Fans

- Increased number of blades can reduce the Tonal Prominence but may increase the broad band noise
- Reduced tip blade clearance can reduce the sound level in small chord blades, long chord are less sensitive to tip clearance

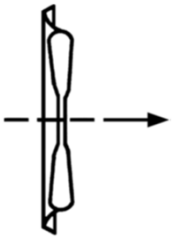


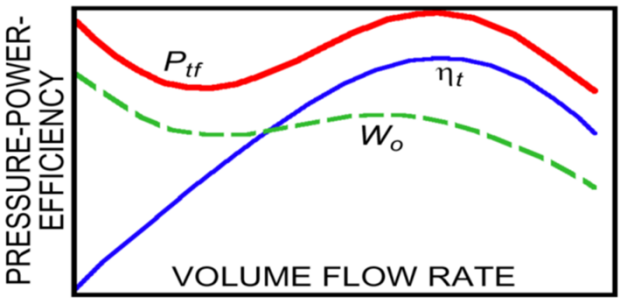


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Propeller Fans

- Vey low pressure and high airflow
- Sound predominantly at blade passing frequency (low frequencies)
- Run into stall if the system pressure increases
- Increased blade chord at the tip with reduced number of blades can reduce the broad band sound level

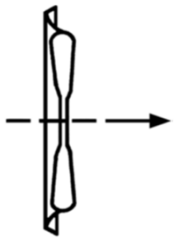


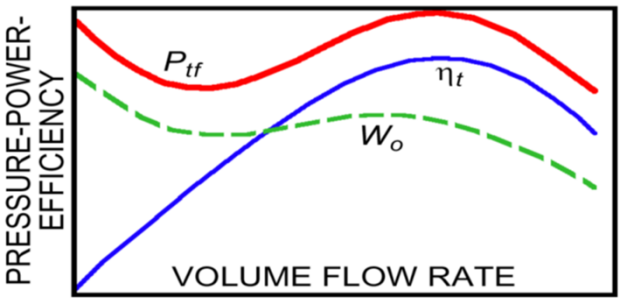


32

Propeller Fans

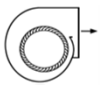
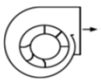
- Curvature of the blades leading edge in the direction of rotation (Swept blades) can reduce the tonal components
- Inlet installation effects like planes close to the inlet 0.25 D or 90° elbows can cause increase in Sound levels of 4 to 8 dB





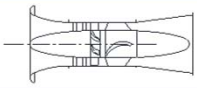
33

Sound Performances

	Centrifugal		
	Fan Type	**Broad Band Noise**	**Discrete Tones**
	Airfoil Backward Curved	Lowest Sound	Moderate
	Backward Curved or Inclined	Low Sound	Moderate
	Plenum Fans	Low Sound	Moderate
	Forward Curved	Moderate Sound	Lowest
	Radial Blades	High Sound	High

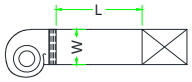
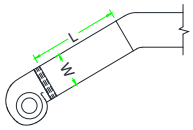
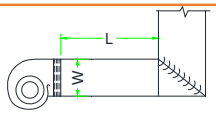
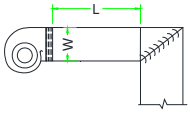
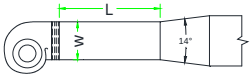
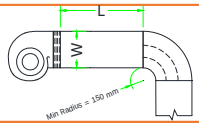
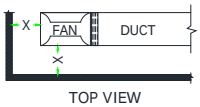
34

Sound Performances

	Axial		
	Fan Type	**Broad Band Noise**	**Discrete Tones**
	Vane Axial	Higher than centrifugal	Moderate to High
	Tube Axial	More than Vane Axial	Moderate to High
	Propeller	Highest	High

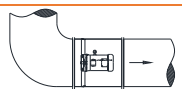
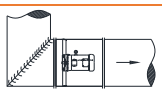
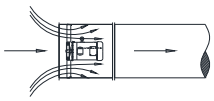
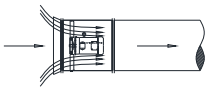
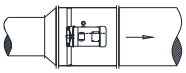
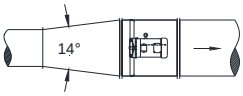
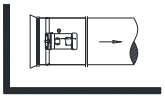
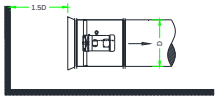
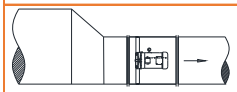
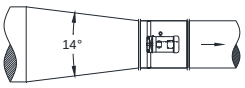
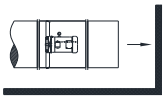
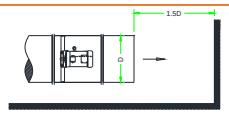
35

Installation Effects on Centrifugal Fans

	Side elbow: straight duct before elbow should be L ≥ 3W		45° bend is preferred to short 90° elbow; Very Good if L ≥ 3W
	Counter-rotating elbow: Bad if L < 3W and Very Bad without turning vanes		
	Down elbow: Fair if 1.5W < L < 3W Bad if L < 1.5 W		Transition angle should be within 14°; L > 1.5W
	Down bend: Fair if 1.5W < L < 3W Bad if L < 1.5 W (if L < 1.5W no turning vanes)		Best if X > 1D Poor if X < 0.75 D Very Poor ix X < 0.5 D

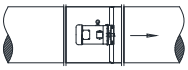
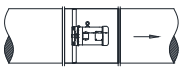
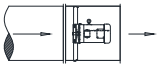
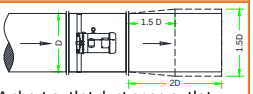
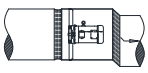
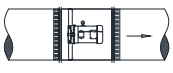
36

Installation Effects on Axial Fans

BAD PRACTICE	GOOD PRACTICE	BAD PRACTICE	GOOD PRACTICE
	 Inlet elbow should be avoided and if present should have long trailing edge turning vanes		 Conical or bellmouth inlets improve air flow at the blade tip
	 Upstream transitions should have an expansion of 14° or less	 Fan inlet obstructions cause inlet turbulences and noises	
 Asymmetrical transitions cause imbalanced load in the fan, turbulences and noises			 Outlet obstructions should be kept at 1.5 D distance

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Installation Effects on Axial Fans

BAD PRACTICE	GOOD PRACTICE	BAD PRACTICE	GOOD PRACTICE
	 Motor downstream of the impeller are preferred to motor upstream to minimize turbulence and noises		 A short outlet duct or an outlet diffuser improve overall fan performances
 Slack/offset flex connections produce turbulences			

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Fan Selection and Installation recommendations

- Most Efficient Fans generally produce less Sound
- Select Fans at the peak efficiency and safe from stall area
- Maintain 1 D clearance at unducted fan inlets and 1.5 D clearances at unducted Fan Outlets
- Ensure good vibration isolation and use of flexible connections
- Fan inlet and outlet transitions should be within 14°
- Ducted elbows, takeoffs, transitions should be 3 D from fan inlet and outlet

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Sound Power Level and Sound Pressure Level

- Sound Sources can be defined by their Sound Power SW [W]
- Sound Power Level SWL or Lw

$$Lw = 10 \times \log(SW / 10^{-12}[W])$$

Source	Sound Power, W	Sound Power Level, dB re 10^{-12} W
Large rocket launch (e.g., space shuttle)	10^8	200
Jet aircraft at takeoff	10^4	160
Large pipe organ	10	130
Small aircraft engine	1	120
Large HVAC fan	0.1	110
Heavy truck at highway speed	0.01	100
Voice, shouting	0.001	90
Garbage disposal unit	10^{-4}	80
Voice, conversation level	10^{-5}	70
Electronic equipment ventilation fan	10^{-6}	60
Office air diffuser	10^{-7}	50
Small electric clock	10^{-8}	40
Voice, soft whisper	10^{-9}	30
Rustling leaves	10^{-10}	20
Human breath	10^{-11}	10

- Receivers perceive Sound Pressure [Pa]
- Sound Pressure Level Lp

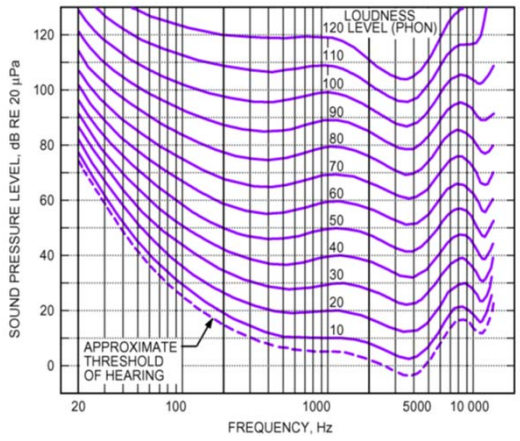
$$Lp = 10 \times \log[(P^2/(20\mu Pa)^2]$$

$$Lp = 20 \times \log(P/20\mu Pa)$$

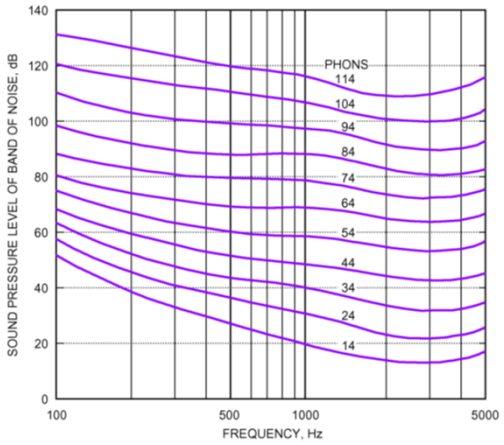
Source	Sound Pressure, Pa	Sound Pressure Level, dB re 20 μPa	Subjective Reaction
Military jet takeoff at 30 m	200	140	Extreme danger
Artillery fire at 3 m	63.2	130	
Passenger jet takeoff at 15 m	20	120	Threshold of pain
Loud rock band	6.3	110	Threshold of discomfort
Automobile horn at 3 m	2	100	
Unmuffled large diesel engine at 40 m	0.6	90	Very loud
Accelerating diesel truck at 15 m	0.2	80	
Freight train at 30 m	0.06	70	Loud
Conversational speech at 1 m	0.02	60	
Window air conditioner at 3 m	0.006	50	Moderate
Quiet residential area	0.002	40	Quiet
Whispered conversation at 2 m	0.0006	30	
Buzzing insect at 1 m	0.0002	20	Perceptible
Threshold of good hearing	0.00006	10	Faint
Threshold of excellent youthful hearing	0.00002	0	Threshold of hearing

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Human response to Sound



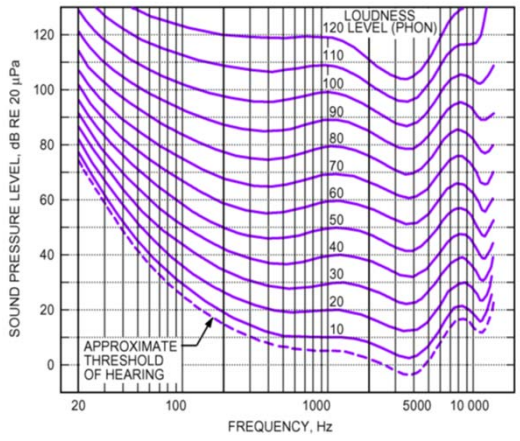
Equal Loudness
Contour for Pure Tones



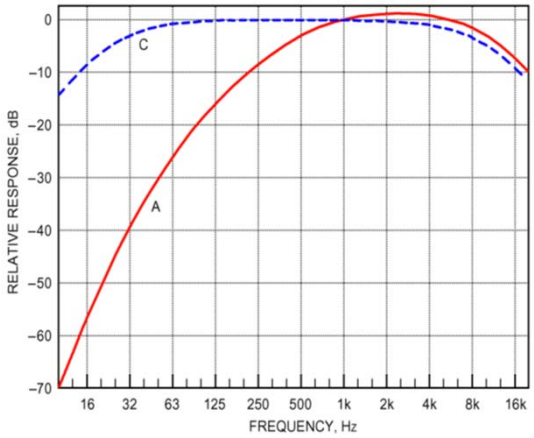
Equal Loudness Contour for
Narrow Bands or Random Noises

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Human response to Sound



Equal Loudness
Contour for Pure Tones



dBA and dBC weighting
correction curves

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Sound Criteria

Sound Pressure Level

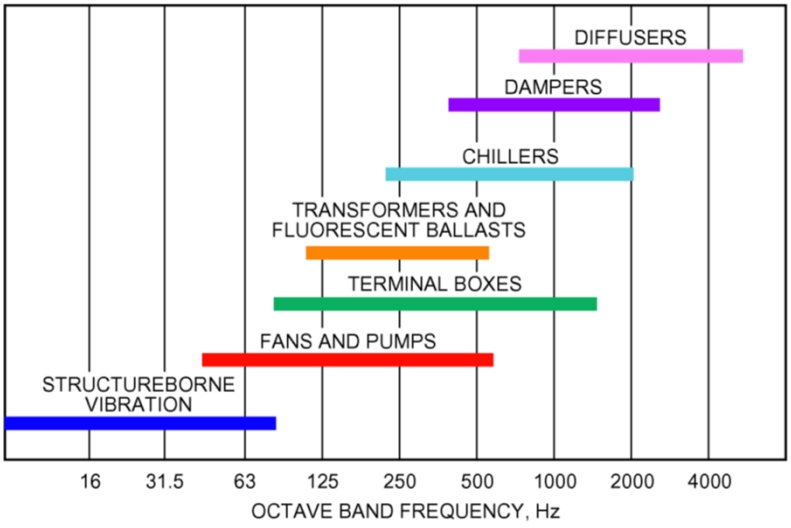
Sound Quality

- Loudness
- Frequency balance
- Tone perception (tone prominence)

Sounds with tones are particularly annoying
High Tone Prominence can cause a relatively low sound to be perceived as noise

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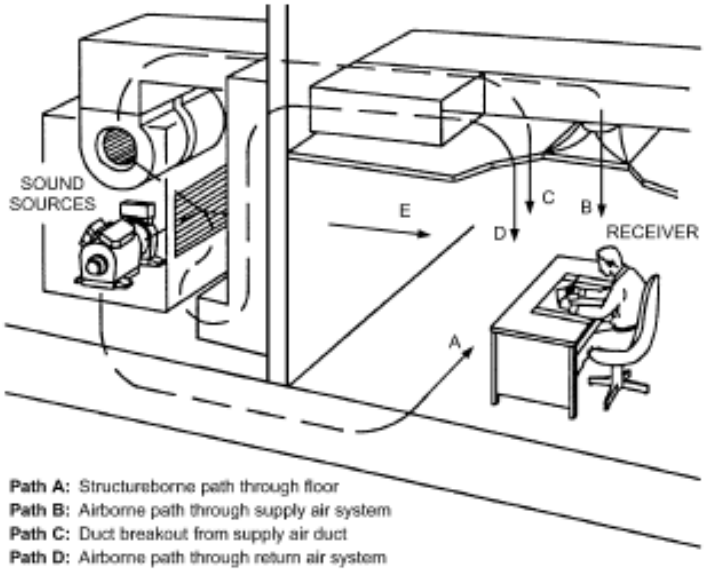
Sound Sources and Frequency Range



Throb	Rumble	Roar	Whistle	Hiss

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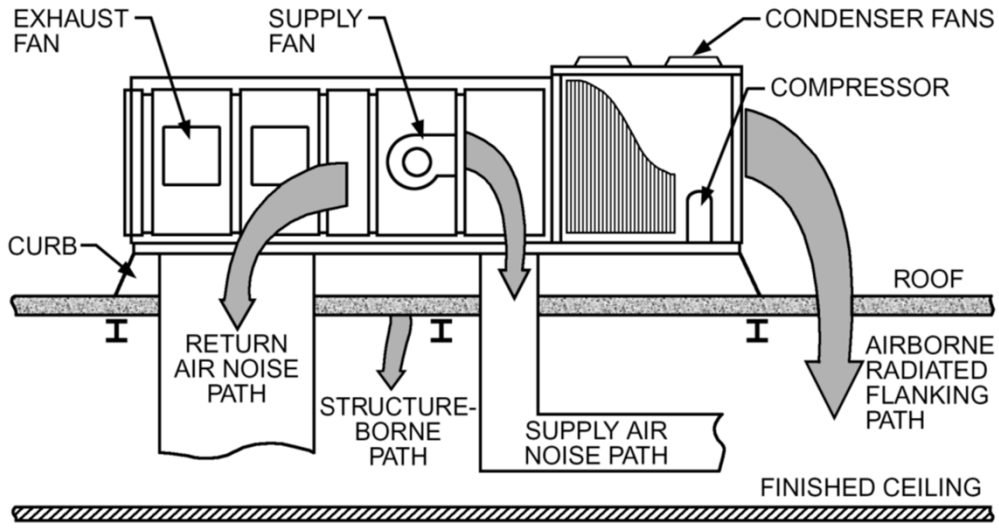
Sound Transmission



Path A: Structureborne path through floor
Path B: Airborne path through supply air system
Path C: Duct breakout from supply air duct
Path D: Airborne path through return air system
Path E: Airborne path through mechanical equipment room wall

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Sound Transmission



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Sound Criteria

A-Weighted Sound Pressure Level dBA

- Single number
- Correlate well with Loudness
- Do not correlate with Sound Quality or Unbalanced Spectrum

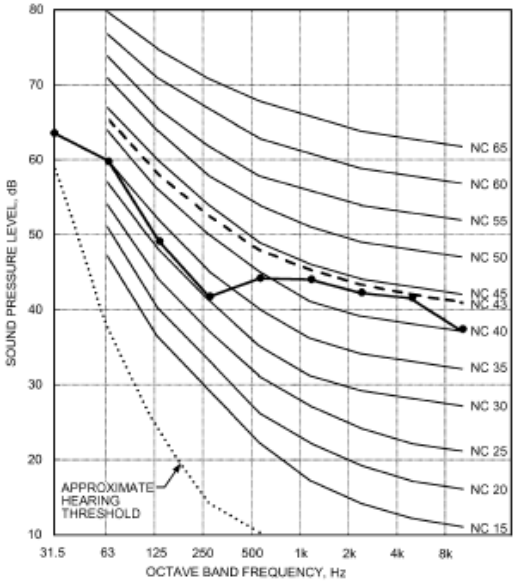
- Used in outdoor environment
- Estimates the risk of hearing damages
- dBC can be included in the specification to account for the low frequency component of the noise

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Sound Criteria

Noise Criteria (NC) Method

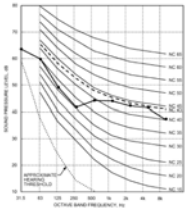
- Method for Rating Noise
- Single number rating
- Correlate with Loudness
- Do not address Sound Quality
- Sources with normal balanced spectrum, sources rumbly or sources hissy, satisfy the same NC but have different effect in the receiver



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Sound Criteria

Noise Criteria (NC) Method



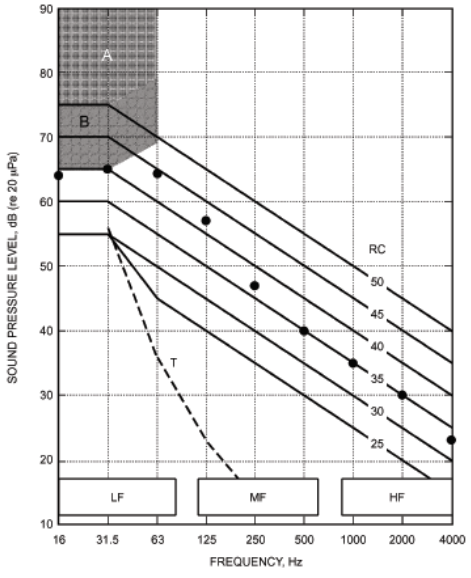
Room Types		Octave Band Analysis[a] NC/RC[b]	Approximate Overall Sound Pressure Level[a] dBA[c]	dBC[c]
Rooms with Intrusion from Outdoor Noise Sources[d]	Traffic noise	N/A	45	70
	Aircraft flyovers	N/A	45	70
Residences, Apartments, Condominiums	Living areas	30	35	60
	Bathrooms, kitchens, utility rooms	35	40	60
Hotels/Motels	Individual rooms or suites	30	35	60
	Meeting/banquet rooms	30	35	60
	Corridors and lobbies	40	45	65
	Service/support areas	40	45	65
Office Buildings	Executive and private offices	30	35	60
	Conference rooms	30	35	60
	Teleconference rooms	25	30	55
	Open-plan offices	40	45	65
	Corridors and lobbies	40	45	65
Courtrooms	Unamplified speech	30	35	60
	Amplified speech	35	40	60
Performing Arts Spaces	Drama theaters, concert and recital halls	20	25	50
	Music teaching studios	25	30	55
	Music practice rooms	30	35	60
Hospitals and Clinics	Patient rooms	30	35	60
	Wards	35	40	60
	Operating and procedure rooms	35	40	60
	Corridors and lobbies	40	45	65
Laboratories	Testing/research with minimal speech communication	50	55	75
	Extensive phone use and speech communication	45	50	70
	Group teaching	35	40	60
Churches, Mosques, Synagogues	General assembly with critical music programs[e]	25	30	55
Schools[f]	Classrooms	30	35	60
	Large lecture rooms with speech amplification	30	35	60
	Large lecture rooms without speech amplification	25	30	55
Libraries		30	35	60
Indoor Stadiums, Gymnasiums	Gymnasiums and natatoriums[g]	45	50	70
	Large-seating-capacity spaces with speech amplification[g]	50	55	75

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Sound Criteria

RC/RC Mark II: Room Criteria Method.

- Diagnostic Tool
- Curves represent well balanced spectra (Neutral)
- The number is the arithmetic average of Lp between 500 1K 2K Hz (speech frequency region) Preferred Speech Interference Level
- Zone A and B indicate area where low frequency noises in excess of 65 or 70 dB are likely to cause vibrations of low mass structures (walls, ceilings, windows)
- 3 areas are identified Low Frequencies, Medium Frequency and High Frequency

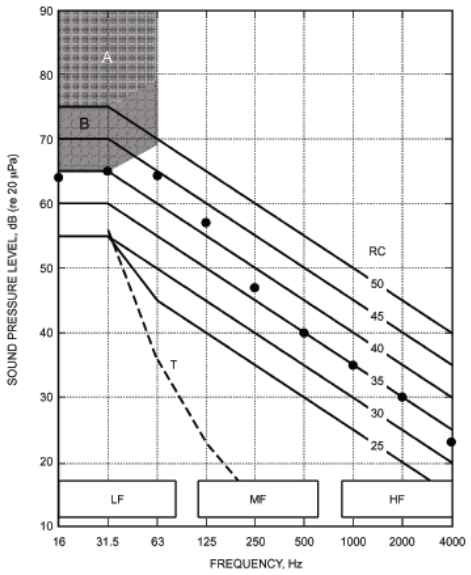


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Sound Criteria

RC/RC Mark II: Room Criteria Method.

- In each area LF MF HF the average deviation of the spectrum from the Neutral Spectrum (1 average value for each range) is calculated
- **Q**uality **A**ssessment **I**ndex is the difference between the max and the min of the 3 deviation values
- For QAI ≤ 5 the quality of the sound is neutral RC 35(N)
- If QAI > 5 the highest positive deviation indicates if the quality is rumbly RC 35(LF), has a roar predominant component RC 35(MF), or is hissy RC 35(HF)
- QAI between 5 and 10 are marginal or border line situations
- QAI > 10 will be unpleasant to the average occupant



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Conclusive remarks

- Most Efficient Fans generally produce less Sound
- Select Fans at the peak efficiency and safe from stall area
- Maintain 1 D clearance at unducted fan inlets and 1.5 D clearance at unducted Fan Outlets
- Ensure good vibration isolation and use of flexible connections
- Fan inlet and outlet transitions should be within 14°
- Ducted elbows, takeoffs, transitions should be 3D from fan inlets and outlets
- Consider the Tonal Prominence effect in sound sensitive applications

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THANK YOU