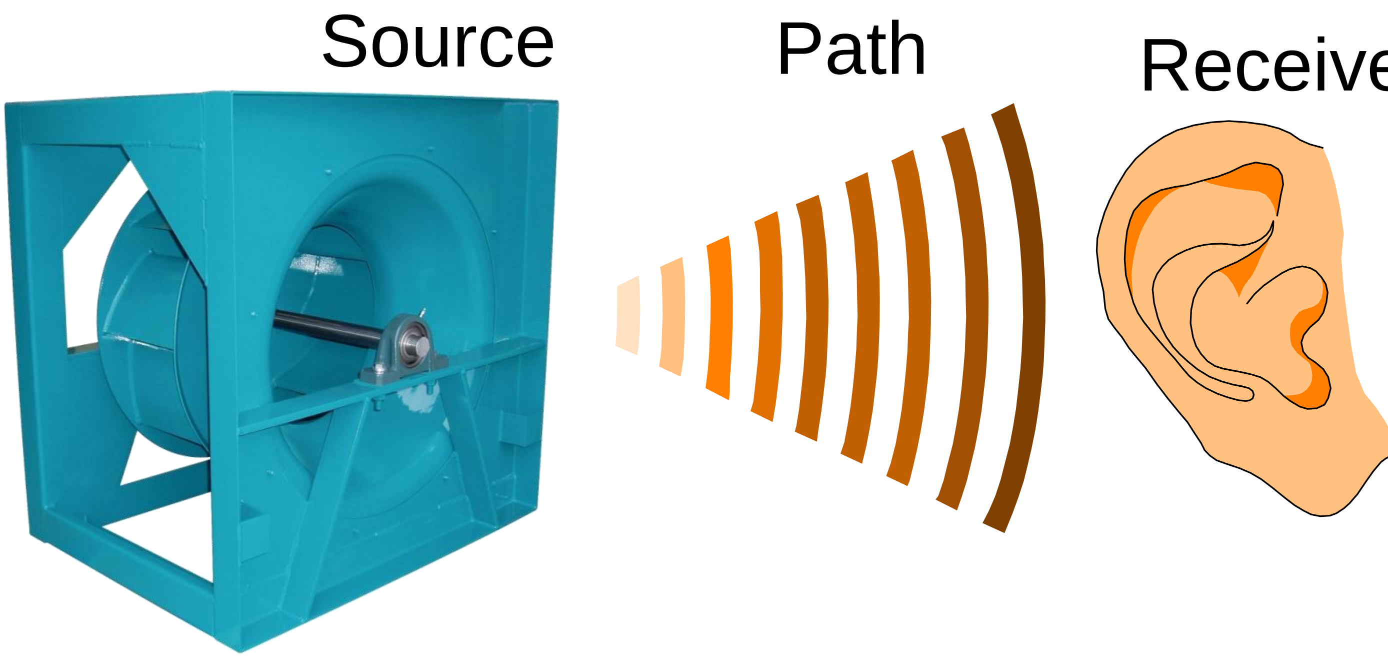
Fan Sound & Sound Ratings

Elements of Sound

- When air is moved, small, repetitive pressure disturbances are imparted to the air
- When these pressure disturbances are sensed by a hearing mechanism (your ear), sound is created



Sound vs Noise - expectations

- When the receiver of sound deems it undesirable, we call it noise
- Perception of sound and sound quantification ranges from ‘voodoo’ or ‘black magic’ to a perfect science by acousticians…will suffice to say I am somewhere in-between.
- Only definitions and basics of sound will be covered here.

Sound vs. Vibration

- The phenomena of sound and vibration are very similar and related
- Sound is caused by the pressure disturbances in an air or gas
- Vibration is caused by similar disturbance of motion in a solid
- The sound pressure disturbance impacting on a solid can impart a vibration
- The vibration of a solid can also result in sound

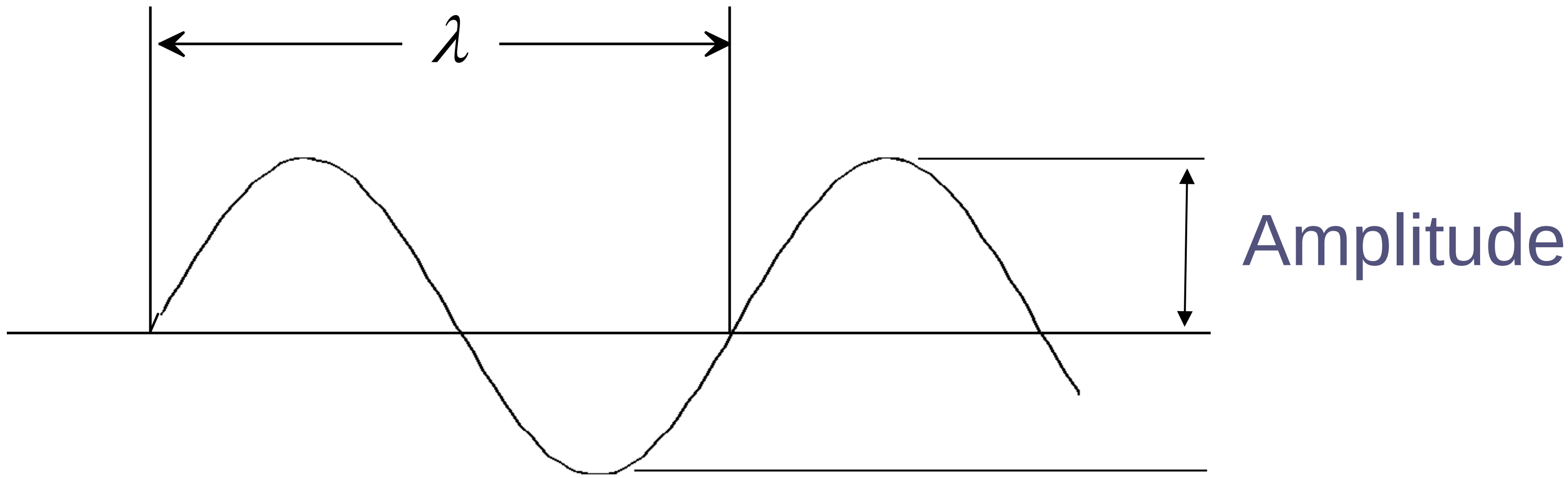
Sound Hearing Limits and Levels, dB (decibel)

- Lower Hearing Limit =
  - .0000000002 bar =
  - 2 x 10^{-5} Pa =
  - 2.9 x 10^{-9} psi =
  - 8 x 10^{-8} in.wg.
- Upper Hearing Limit =
  - 1.0 bar =
  - 100,000 Pa =
  - 14.5 psi =
  - 401 in.wg.

- Decibel, dB = 10 * log (Dimensionless Ratio of Power or ‘Power like’ quantities)
  - dB = 10 $\log_{10}$ (W / Wref)

Sound Amplitude

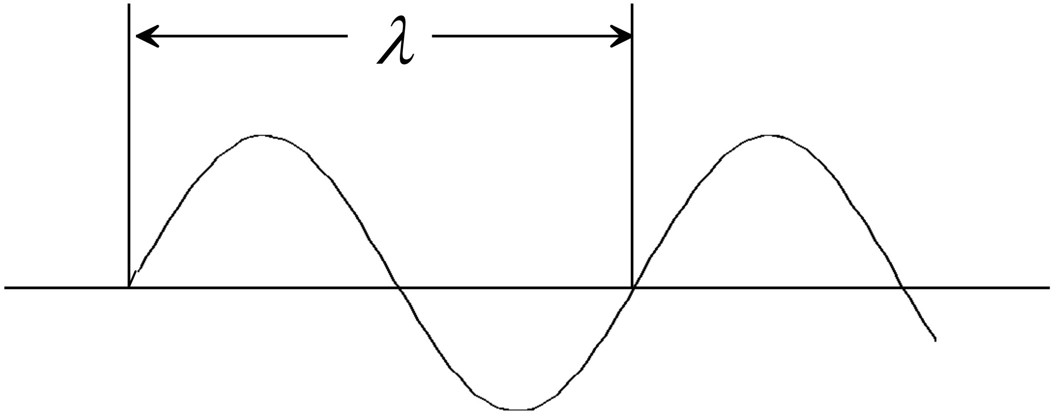
- Amplitude - The amount the pressure oscillations deviate about the mean pressure



Sound Frequency

- Frequency, f
  - The number of pressure peaks per second that a sound exhibits
  - Measured in Hertz (Hz)
- Speed of sound, c
- Wavelength, λ

$$\lambda = c/f$$



FREQUENCY (f)	λ
100 Hz	3.5 m, 10 ft.
1000 Hz	0.35 m, 1 ft.
10,000 Hz	0.035 m, 0.1 ft.

Sound Frequency

- Sound spectrum: the human ear is sensitive to frequencies between 20 and 20,000 Hz
- For fans, frequencies between 45 and 11,000 Hz are of interest
- Reasons the frequency characteristic of sound rating ratings is used:
  - Sound at different frequencies behaves differently
  - Human ear responds differently to different frequencies of sound

Octave Band Frequencies

- Audible sound is divided into 8 octave bands
- Starting at 63 Hz, each succeeding octave band has a center frequency twice the previous band
- Sound Level is defined for every fan operating point by a spectrum of frequencies as below:

Octave Bands	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Frequency Range (Hz)	45 to 90	90 to 180	180 to 355	355 to 700	710 to 1400	1400 to 2800	2800 to 4600	5600 to 11200
Center Frequency (Hz)	63	125	250	500	1000	2000	4000	8000

Separating Octave Band Frequencies

- How do we analyze sound at different frequencies?
  - Electrical filters are used that allow only the frequencies within the desired octave band to pass though, while others are blocked
  - When combined with a microphone and metering circuitry, you have a “sound octave band analyzer”
- This method is accepted by AMCA
- Other methods of separating sound by frequency are also in use today

Sound Power Level, Lw dB

- Sound power level
  - The acoustical power radiating from a source
  - Describes the total amount of acoustical energy the fan emits
  - Similar to the watt rating of a light bulb which describes the total amount of energy the light emits
  - This value is independent of location, distance and environment
  - Sound power cannot be measured directly
  - Sound power is usually expressed in decibels with a reference level to 10–12 watts (or 1 Picowatt). It is the log ratio of 2 ‘power like’ quantities:

Lw (dB) = $10\log_{10}$ (W / Wref)

Where, Wref = 1 pW = 10^{-12} Watts

Sound Power

- Typical sound power levels:

Source	**Typical Sound Power Level, Lw (dB re 1 pW)**	**Power (W)**
Saturn Rocket	180	1,000,000
Turbojet engine with afterburner	170	100,000
Turbojet engine, 7000 lb thrust	160	10,000
4 Engine Propeller aircraft	140	100
75 piece orchestra	130	10
Large chipping hammer	120	1
Auto horn	110	.1
Radio	100	.01
Shouting voice	90	.001
Open Office	80	.0001
Conversational voice	70	.00001
Bedroom	60	.000001
Whisper	50	.0000001

Sound Pressure Level, Lp dB

- Sound pressure level
  - The amplitude of pressure oscillations at some location
  - Describes the loudness level of the sound
  - Like the brightness level (lumens) of a light bulb at some location
  - This value varies with the distance from the sound source and is affected by the environment surrounding the source
  - Easily measured directly with a meter
  - Sound pressure is usually expressed in decibels with a reference level of 20 m Pa

$Lp\ (dB) = 10\log_{10}(P^2 / Pref^2) = 20\log_{10}(P / Pref)$

Where, $Pref = 20\ \mu\ Pa$

Sound Pressure

- Typical sound pressure levels

PRESSURE (MICROBAR)	**PRESSURE Level (db)**	**SOURCE (LONG TIME AVERAGE)**
200,000	180	ROCKET LAUNCH AT PAD (3 PSI)
2,000*	140	JET PLANE *APPROX. 1* H2O
	130	THRESHOLD OF PAIN
200	120	THRESHOLD OF DISCOMFORT, LOUD BAND, RIVETING
	110	BLARING RADIO, AUTOMOBILE HORN
20	100	STEEL SAW
	90	PUNCH PRESS, AUTOMOBILE AT 40 MPH IN HEAVY CITY TRAFFIC
2	80	RELATIVELY QUIET FACTORY
	70	QUIET AUTOMOBILE, CONVERSATIONAL SPEECH
0.2	60	NOISY RESIDENCE (INSIDE)
	50	QUIET RESIDENCE (INSIDE)
0.02	30	QUIET WHISPER AT 5 FEET
0.002	20	ELECTRIC CLOCK
0.0002	0	THRESHOLD OF HEARING

What is dBA?

- dBA: The estimated sound pressure level in the space at a certain distance from the sound source using “A” weighting (all octave bands combined)

A-Weighting

- A human’s ability to perceive sound varies with its frequency
- ‘A’ weighting adjusts the sound power level for the response of the human ear - LwA
- ‘A’ weighting is also used in the calculation of sound pressure levels - LpA

A-weighting Corrections

Band Center Frequency (Hz)	One-Third-Octave-Band Weightings (dB)	Octave-Band Weightings (dB)
50	−30.2	—
63	−26.2	−26.2
80	−22.5	—
100	−19.1	—
125	−16.1	−16.1
160	−13.4	—
200	−10.9	—
250	−8.6	−8.6
315	−6.6	—
400	−4.8	—
500	−3.2	−3.2
630	−1.9	—
800	−0.8	—
1,000	0.	0.
1,250	0.6	—
1,600	1.0	—
2,000	1.2	1.2
2,500	1.3	—
3,150	1.2	—
4,000	1.0	1.0
5,000	0.5	—
6,300	−0.1	—
8,000	−1.1	−1.1
10,000	−2.5	—

What is LwA?

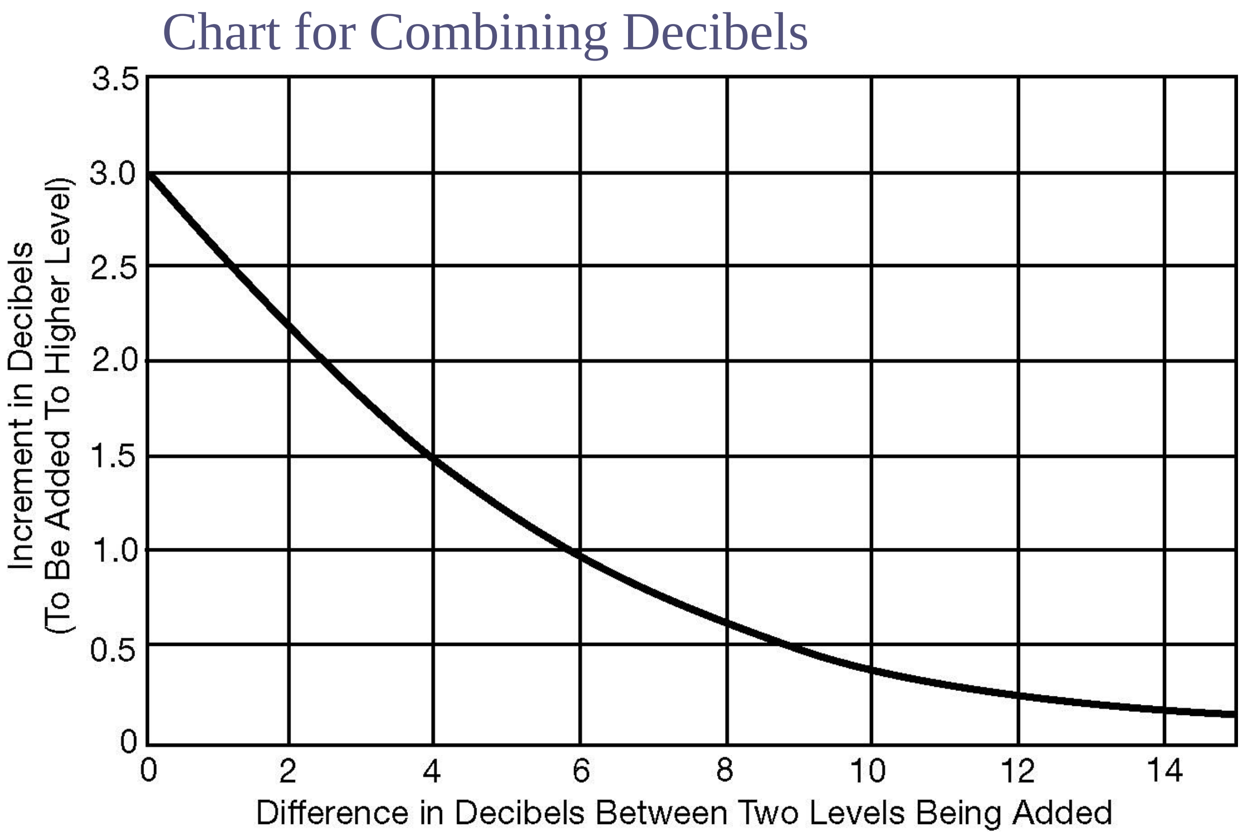
- The 8 octave band sound power levels can be reduced to one number (LwA).
- The LwA value represents the logarithmic summation of all 8 octave band values, ‘A weighted’ to account for the response of the human ear.
  - Log summation: $L_w = 10 \log (10^{Lw1/10} + .. 10^{Lw8/10})$

Row	Octave Band	1	2	3	4	5	6	7	8	LwA
1	Lw at Inlet	99	98	94	91	88	84	79	73	
2	A weighting	-26.2	-16.1	-8.6	-3.2	0	1.2	1	-1.1	
3	Lw A weighted	72.8	81.9	85.4	87.8	88	85.2	80	71.9	93

Note: Although Lw (row 1) in bands 1-3 are significantly higher than Lw A weighted (row 3) the human ear will always perceive the sound as LwA = 93. Thus it does not make too much sense in saying band 1 is 26 dB ‘lower’ or ‘quieter’ when 2 fans are compared.

Chart for Combining Decibels

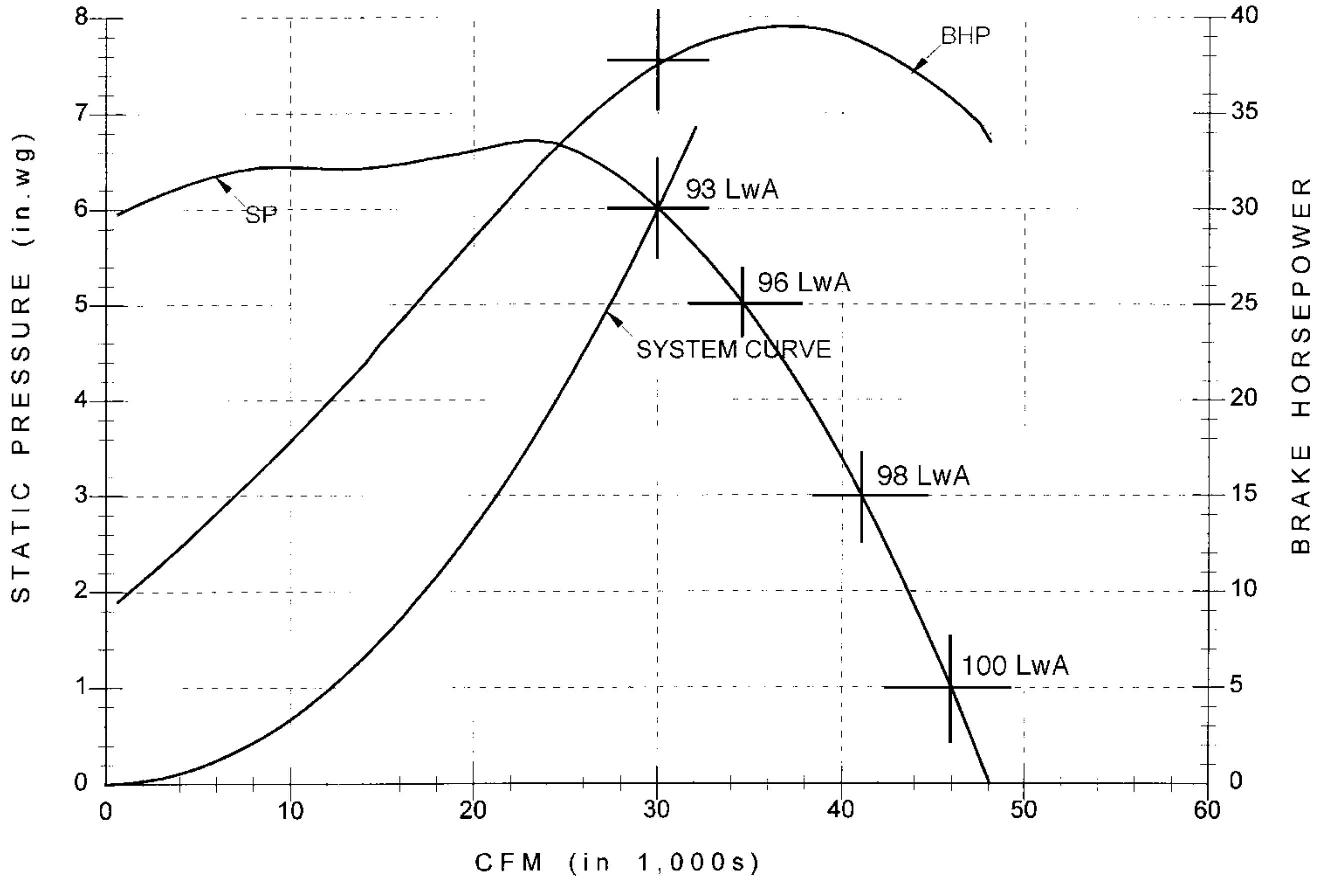
- Sound Levels (dB) are combined by logarithmic addition



Point of Operation - LwA

- LwA is usually lowest at most efficient operation point

Example: Size 445, backward inclined centrifugal, 913 RPM



What is a Sone?

- A sone is the unit of loudness
  - 1 sone is the loudness of a sound of Lp= 40 dB re 20μPa at 1KHz
- A value in sones doubles when the sound is perceived as twice as loud
- An increase in sound pressure of 9-10 dB doubles the sone rating
- Useful for comparing relative sound output of two fans

Calculating Sones - Loudness Index

- From Lw determine Lp at 5 ft in a hemispherical free field using

Lp=Lw-11.5

- For this Lp determine loudness indices from table for each octave band (s1-8)

- Sones,

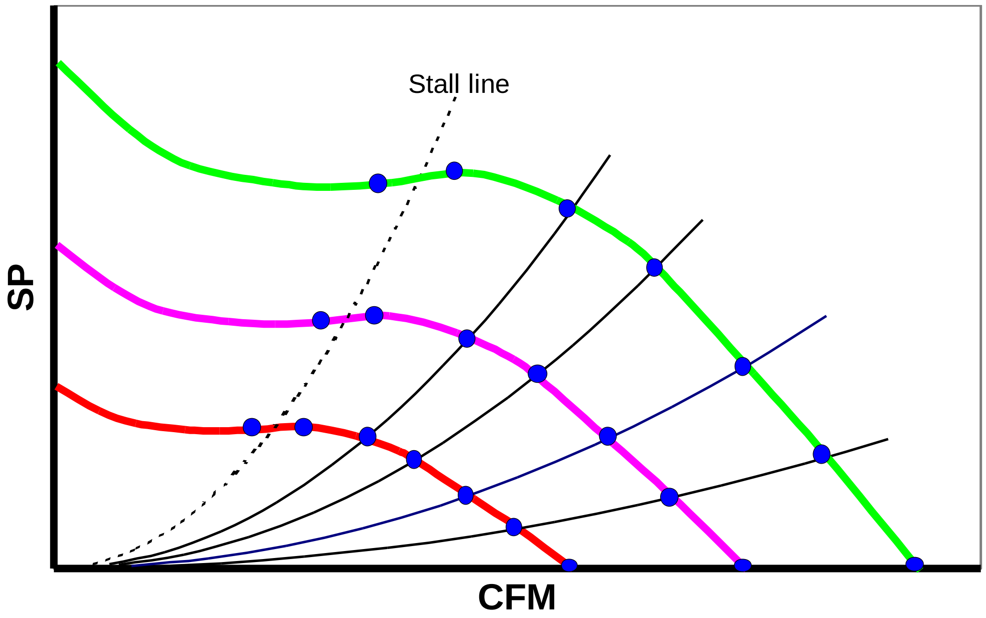
$S = \phi\,(s1\text{-}8)$

Lp	OCTAVE BAND							
	63	125	250	500	1000	2000	4000	8000
11								0.18
12							0.1	0.22
13							0.14	0.26
14							0.18	0.3
15						0.1	0.22	0.35
16						0.14	0.26	0.4
17						0.18	0.3	0.45
18					0.1	0.22	0.35	0.5
19					0.14	0.26	0.4	0.55
20					0.18	0.3	0.45	0.61
21					0.22	0.35	0.5	0.67
22					0.26	0.4	0.55	0.73
23				0.12	0.3	0.45	0.61	0.8
24				0.16	0.35	0.5	0.67	0.87
25				0.21	0.4	0.55	0.73	0.94
26				0.26	0.45	0.61	0.8	1.02
27				0.31	0.5	0.67	0.87	1.1
28				0.37	0.55	0.73	0.94	1.18
29			0.12	0.43	0.61	0.8	1.02	1.27
30			0.16	0.49	0.67	0.87	1.1	1.35
31			0.21	0.55	0.73	0.94	1.18	1.44
32			0.26	0.61	0.8	1.02	1.27	1.54
33			0.31	0.67	0.87	1.1	1.35	1.64
34			0.37	0.73	0.94	1.18	1.44	1.75
35		0.12	0.43	0.8	1.02	1.27	1.54	1.87
36		0.16	0.49	0.87	1.1	1.35	1.64	1.99
37		0.21	0.55	0.94	1.18	1.44	1.75	2.11
38		0.26	0.62	1.02	1.27	1.54	1.87	2.24
39		0.31	0.69	1.1	1.35	1.64	1.99	2.38
40		0.37	0.77	1.18	1.44	1.75	2.11	2.53
41	0.12	0.43	0.85	1.27	1.54	1.87	2.24	2.68
42	0.16	0.49	0.94	1.35	1.64	1.99	2.38	2.84
43	0.21	0.55	1.04	1.44	1.75	2.11	2.53	3
44	0.26	0.62	1.13	1.54	1.87	2.24	2.68	3.2
45	0.31	0.69	1.23	1.64	1.99	2.38	2.84	3.4
46	0.37	0.77	1.33	1.75	2.11	2.53	3	3.6
47	0.43	0.85	1.44	1.87	2.24	2.68	3.2	3.8
48	0.49	0.94	1.56	1.99	2.38	2.84	3.4	4.1
49	0.55	1.04	1.68	2.11	2.53	3	3.6	4.3
50	0.62	1.13	1.82	2.24	2.68	3.2	3.8	4.6
51	0.69	1.23	1.96	2.38	2.84	3.4	4.1	4.9
52	0.77	1.33	2.11	2.53	3	3.6	4.3	5.2
53	0.85	1.44	2.24	2.68	3.2	3.8	4.6	5.5
54	0.94	1.56	2.38	2.84	3.4	4.1	4.9	5.8
55	1.04	1.68	2.53	3	3.6	4.3	5.2	6.2
56	1.13	1.82	2.68	3.2	3.8	4.6	5.5	6.6
57	1.23	1.96	2.84	3.4	4.1	4.9	5.8	7
58	1.33	2.11	3	3.6	4.3	5.2	6.2	7.4
59	1.44	2.27	3.2	3.8	4.6	5.5	6.6	7.8
60	1.56	2.44	3.4	4.1	4.9	5.8	7	8.3
61	1.68	2.61	3.6	4.3	5.2	6.2	7.4	8.8
62	1.82	2.81	3.8	4.6	5.5	6.6	7.8	9.3
63	1.96	3	4.1	4.9	5.8	7	8.3	9.9
64	2.11	3.2	4.3	5.2	6.2	7.4	8.8	10.5
65	2.27	3.5	4.6	5.5	6.6	7.8	9.3	11.1

Lp	OCTAVE BAND							
	63	125	250	500	1000	2000	4000	8000
66	2.44	3.7	4.9	5.8	7	8.3	9.9	11.8
67	2.61	4	5.2	6.2	7.4	8.8	10.5	12.6
68	2.81	4.3	5.5	6.6	7.8	9.3	11.1	23.5
69	3	4.7	5.8	7	8.3	9.9	11.8	14.4
70	3.2	5	6.2	7.4	8.8	10.5	12.6	15.3
71	3.5	5.4	6.6	7.8	9.3	11.1	13.5	16.4
72	3.7	5.8	7	8.3	9.9	11.8	14.4	17.5
73	4	6.2	7.4	8.8	10.5	12.6	15.3	18.7
74	4.3	6.6	7.8	9.3	11.1	13.5	16.4	20
75	4.7	7	8.3	9.9	11.8	14.4	17.5	21.4
76	5	7.4	8.8	10.5	12.6	15.3	18.7	23
77	5.4	7.8	9.3	11.1	13.5	16.4	20	24.7
78	5.8	8.3	9.9	11.8	14.4	17.5	21.4	26.5
79	6.2	8.8	10.5	12.6	15.3	18.7	23	28.5
80	6.7	9.3	11.1	13.5	16.4	20	24.7	30.5
81	7.2	9.9	11.8	14.4	17.5	21.4	26.5	33
82	7.7	10.5	12.6	15.3	18.7	23	28.5	35.3
83	8.2	11.1	13.5	16.4	20	24.7	30.5	38
84	8.8	11.8	14.4	17.5	21.4	26.5	33	41
85	9.4	12.6	15.3	18.7	23	28.5	35.3	44
86	10	13.5	16.4	20	24.7	30.5	38	48
87	10.8	14.4	17.5	21.4	26.5	33	41	52
88	11.7	15.3	18.7	23	28.5	35.3	44	56
89	12.6	16.4	20	24.7	30.5	38	48	61
90	13.6	17.5	21.4	26.5	33	41	52	66
91	14.7	18.7	23	28.5	35.3	44	56	71
92	16	20	24.7	30.5	38	48	61	77
93	17.3	21.4	26.5	33	41	52	66	83
94	18.7	23	28.5	35.3	44	56	71	90
95	20	24.7	30.5	38	48	61	77	97
96	21.4	26.5	33	41	52	66	83	105
97	23	28.5	35.3	44	56	71	90	113
98	24.7	30.5	38	48	61	77	97	121
99	26.5	33	41	52	66	83	105	130
100	28.5	35.3	44	56	71	90	113	139
101	30.5	38	48	61	77	97	121	149
102	33	41	52	66	83	105	130	160
103	35.3	44	56	71	90	113	139	171
104	38	48	61	77	97	121	149	184
105	41	52	66	83	105	130	160	197
106	44	56	71	90	113	139	171	211
107	48	61	77	97	121	149	184	226
108	52	66	83	105	130	160	197	242
109	56	71	90	113	139	171	211	260
110	61	77	97	121	149	184	226	278
111	66	83	105	130	160	197	242	298
112	71	90	113	139	171	211	260	320
113	77	97	121	149	184	226	278	
114	83	105	130	160	197	242	298	
115	90	113	139	171	211	260	320	
116	97	121	149	184	226	278		
117	105	130	160	197	242	298		
118	113	139	171	211	260	320		
119	121	149	184	226	278			
120	130	160	197	242	298			

Fan Sound Ratings

- Fan sound ratings are normally based on <u>sound power levels</u>
  - These ratings are independent of the environment
  - AMCA test standards (like AMCA 300-05, 301-05) are used to establish sound power levels



Example of AMCA std 300 test output

TWIN CITY FAN COMPANIES, INC.
5959 TRENTON LANE
PLYMOUTH, MN 55442-3238

Page 6

TEST NAME : 18CDD11

POINT OF OPERATION 1	SPS = 0.65 %WOV = 94	APS = 0.0 BP = 29.2	RPM = 2100 TI = 74.8	CFMest = 5439 Density = 0.072
POINT OF OPERATION 2	SPS = 2.5 %WOV = 77	APS = 2.41 BP = 29.2	RPM = 2100 TI = 74.8	CFMest = 4439 Density = 0.072
POINT OF OPERATION 3	SPS = 3.99 %WOV = 59	APS = 3.71 BP = 29.2	RPM = 2100 TI = 74.8	CFMest = 3399 Density = 0.072

AMCA BAND NO.	1	2	3	4	5	6	7	8
CENTER FREQUENCY (HZ)	63	125	250	500	1000	2000	4000	8000
Lwi 1	79	80	88	86	81	81	80	74
Lwi 2	79	80	91	83	78	77	73	72
Lwi 3	81	81	87	81	76	74	72	73

The following data have been converted to A weighted sound powers.

AMCA BAND NO.	1	2	3	4	5	6	7	8
CENTER FREQUENCY (HZ)	63	125	250	500	1000	2000	4000	8000
LwA 1	53	65	80	83	81	82	81	73
LwA 2	54	65	83	80	78	78	74	71
LwA 3	55	65	78	78	76	75	73	72

Total A weighted sound power.
LwtA 1 89
LwtA 2 87
LwtA 3 84

Sones at 5 feet.
SONES 1 = 28
SONES 2 = 25
SONES 3 = 22

0 POINTS ARE WITHIN 6 dB OF THE BACKGROUND

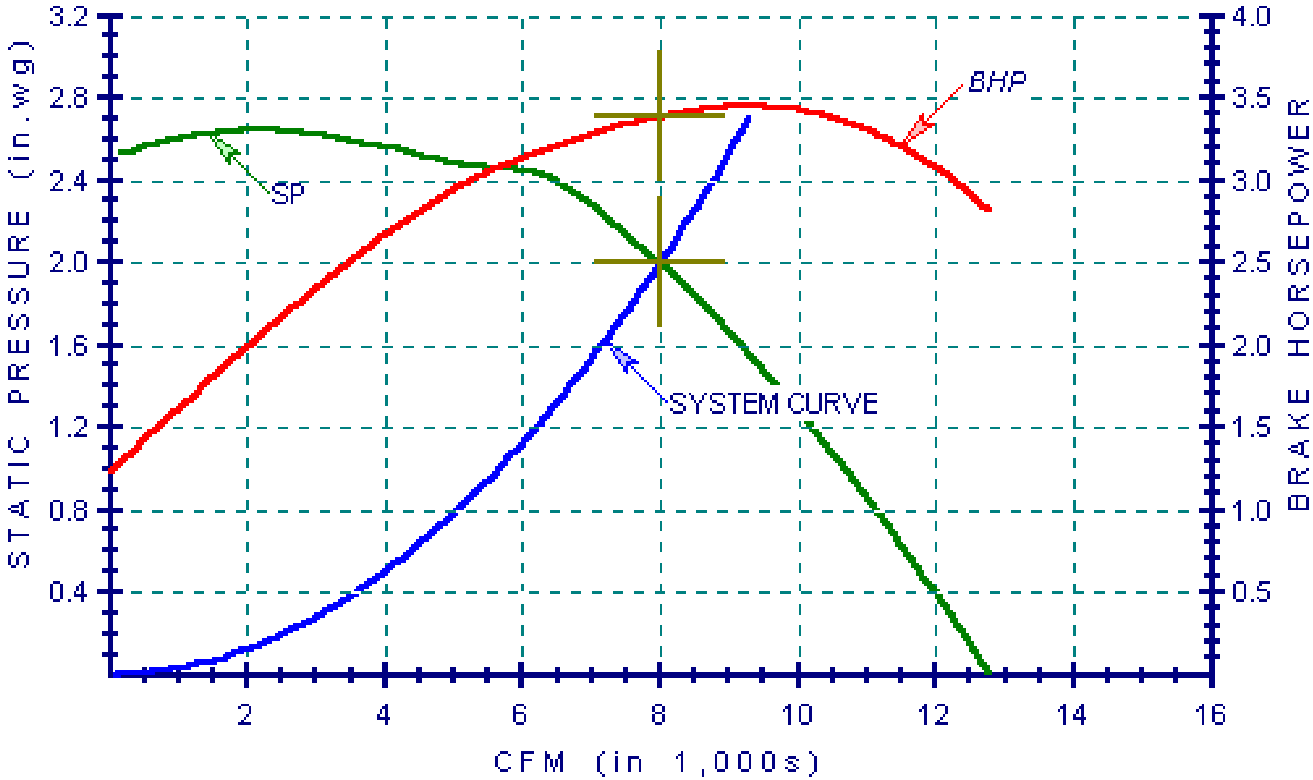
THIS TEST DATA OBTAINED IN A LABORATORY ACCREDITED BY AMCA FOR AMCA STANDARD 300, REVERBERANT ROOM METHOD FOR SOUND TESTING OF FANS. DATA IS NOT CERTIFIED BY AMCA

Fan Sound Ratings - Example

Customer:	Fan Tag:
Job ID:	Model: 300 BAF-SW

CFM:	8,000
SP:	2 in.wg
RPM:	899
BHP:	3.39
Outlet Velocity:	1,547
Density:	0.075

TWIN CITY FAN AND BLOWER PERFORMANCE CURVE



Inlet Sound Power

Octave	Level
1	89
2	89
3	84
4	78
5	76
6	71
7	65
8	60

in db re 10^{-12} watts

4/19/02 15:41 #74

Fan Sound Specifications

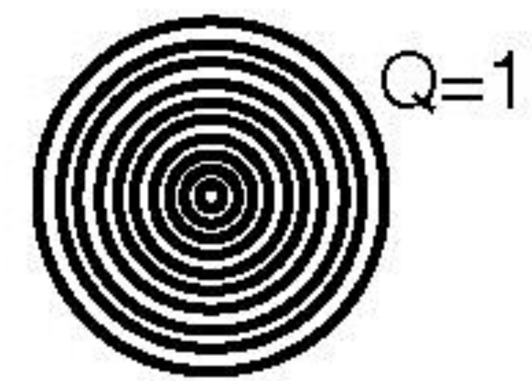
- Fan sound specifications are normally based on sound pressure levels
  - This value varies with the distance from the sound source and the environment surrounding the source
- Sound specifications are intended to:
  - Limit annoyances
  - Prevent health damage
  - E.G. - OSHA limit of 85 dBA - 8 hour exposure is a pressure level

Determining Sound Pressure Levels

- Can be a complicated calculation, and is normally a job for an acoustician
  - Sound pressure varies with distance from source
  - Sound pressure varies with “number of” and “hardness of” reflecting walls
  - Sound pressure varies with frequency of the sound
- Sound pressure (dBA) can be estimated with:
  - Sound power level (LwA)
  - Directivity factor (Q)
  - Distance from source (in feet)

Fan Sound Radiation

- Without any nearby reflective surfaces (i.e. floor, wall or ceiling), sound radiates in a spherical pattern
- If the fan is on a flat plane (i.e. floor, wall or ceiling), sound will radiate in a hemispherical pattern

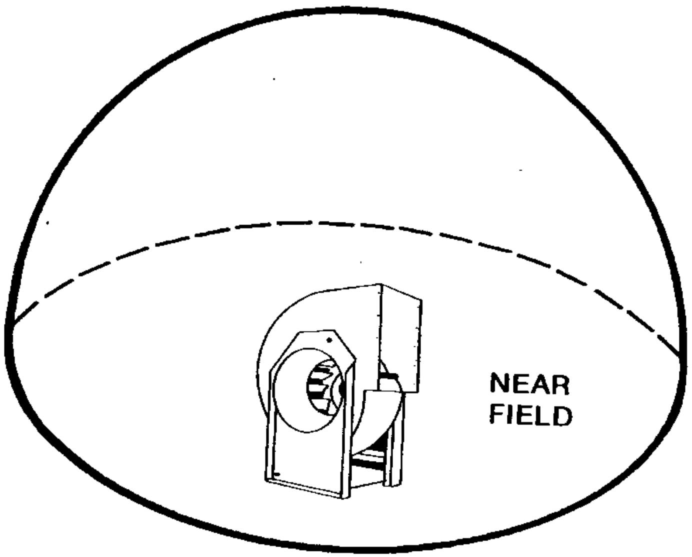


Uniform Spherical Radiation

Uniform Hemispherical Radiation

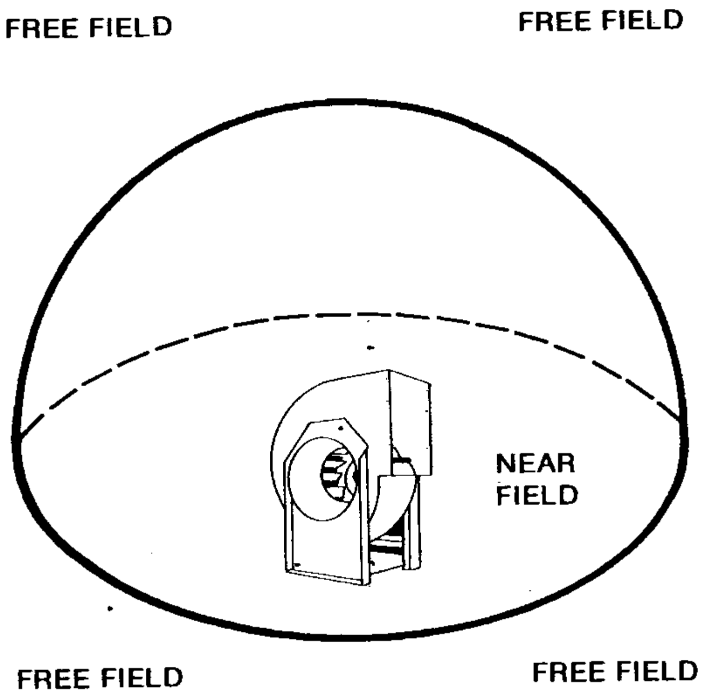
“Near Field” Conditions

- Near field conditions exist close to the fan
- In the near field, sound generated at one area will tend to interfere with sound generated at other areas
- Thus, near field measurements can be misleading



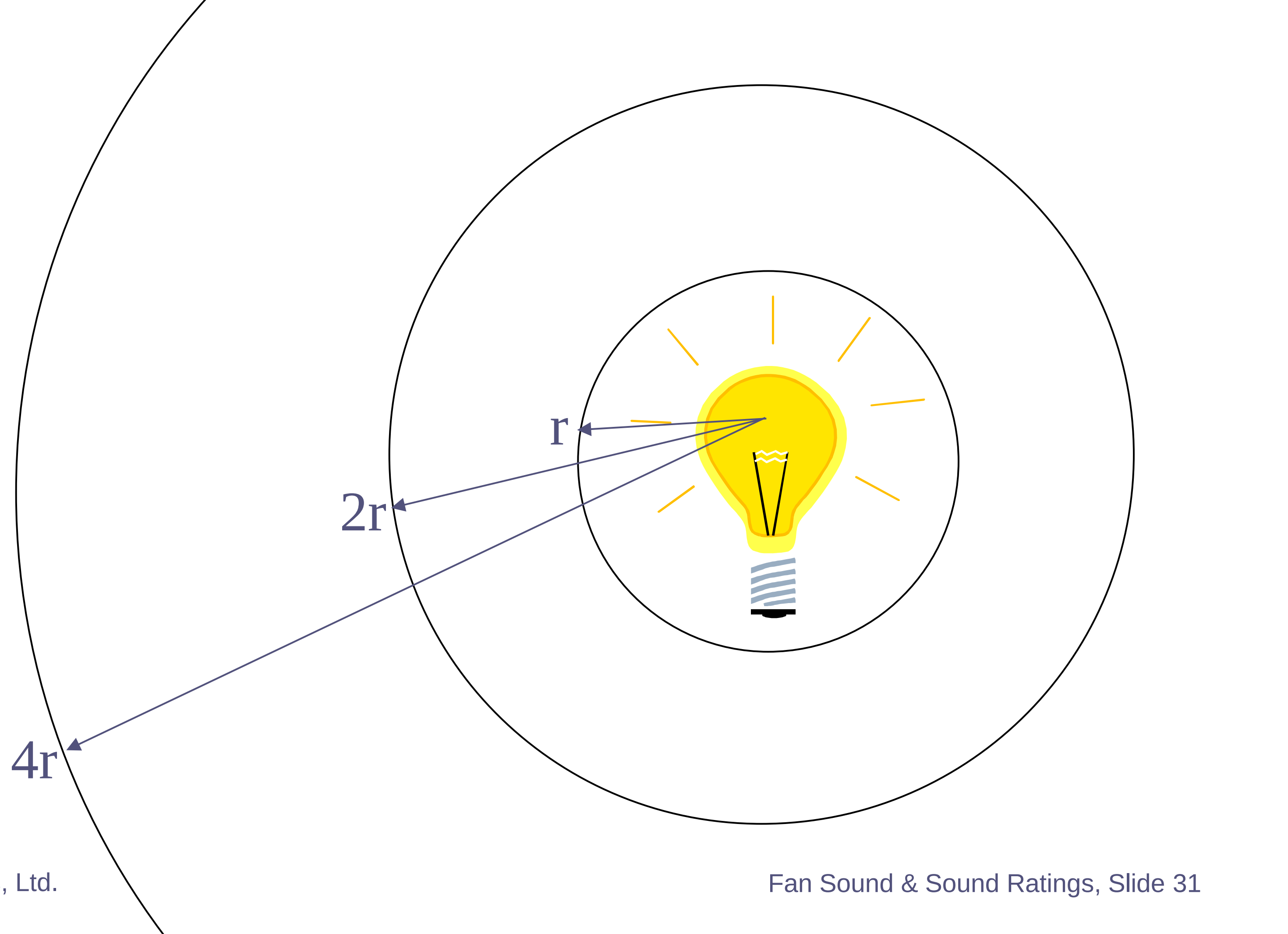
“Free Field” Conditions

- Free field conditions exist beyond the near field, considered to begin at least one wavelength away from fan
- Free field sound radiates in a hemispherical pattern



Sound Pressure

- Sound pressure level will decay 6dB for each doubling of the distance from the fan



“Reverberant Field” Conditions

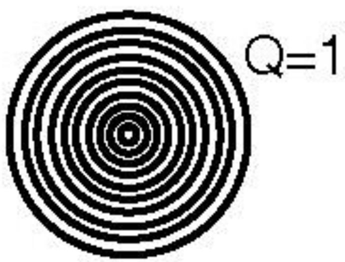
- In a room there are multiple reflective surfaces
- The pressure will cease to decrease significantly as you move beyond a certain distance
- This area of relatively constant pressure is called the “reverberant field”
- AMCA std 300 Lp measurements are done in a reverberant field- similar to TCF sound lab
- Lw (fan) is calculated from Lp (fan) by the method of substitution by using a calibrated RSS (reference sound source):
  - Lw (fan) = Lp (fan) + Lw (RSS) – Lp (RSS)

Directivity

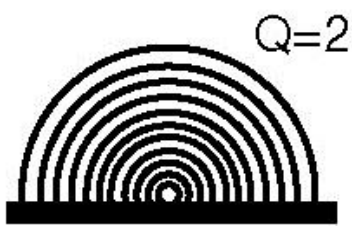
- Location
  - If you are sitting 3 ft. directly in front of a speaker, sound is louder than if you were sitting 3 ft. behind it
  - Fans also radiate varying sounds at different locations, despite being the same distance away
  - However, this effect is difficult to measure and usually ignored
- Reflective surfaces
  - Hard surfaces near the fan also affect directivity and are included in sound power estimates
  - It is usually assumed that all sound reflects, and that each additional wall doubles the pressure (adds 3 dB)

Directivity Factor

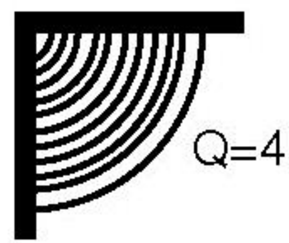
- Number of reflective surfaces:
  - Q = 1 No reflecting surfaces
  - Q = 2 One wall (or floor)
  - Q = 4 Two walls (or floor and one wall)
  - Q = 8 Three walls (located in a corner)



Uniform Spherical Radiation



Uniform Hemispherical Radiation



Uniform Radiation over 1/4 of Sphere

Typical Fan Installations

- Four types of typical fan installations used for testing purposes (ref AMCA std 303-79)
  - Type A
  - Type B
  - Type C
  - Type D
- Should be used for only routine design jobs
- In cases, where the acoustic design is critical, more refined methods should be applied

Installation Type A

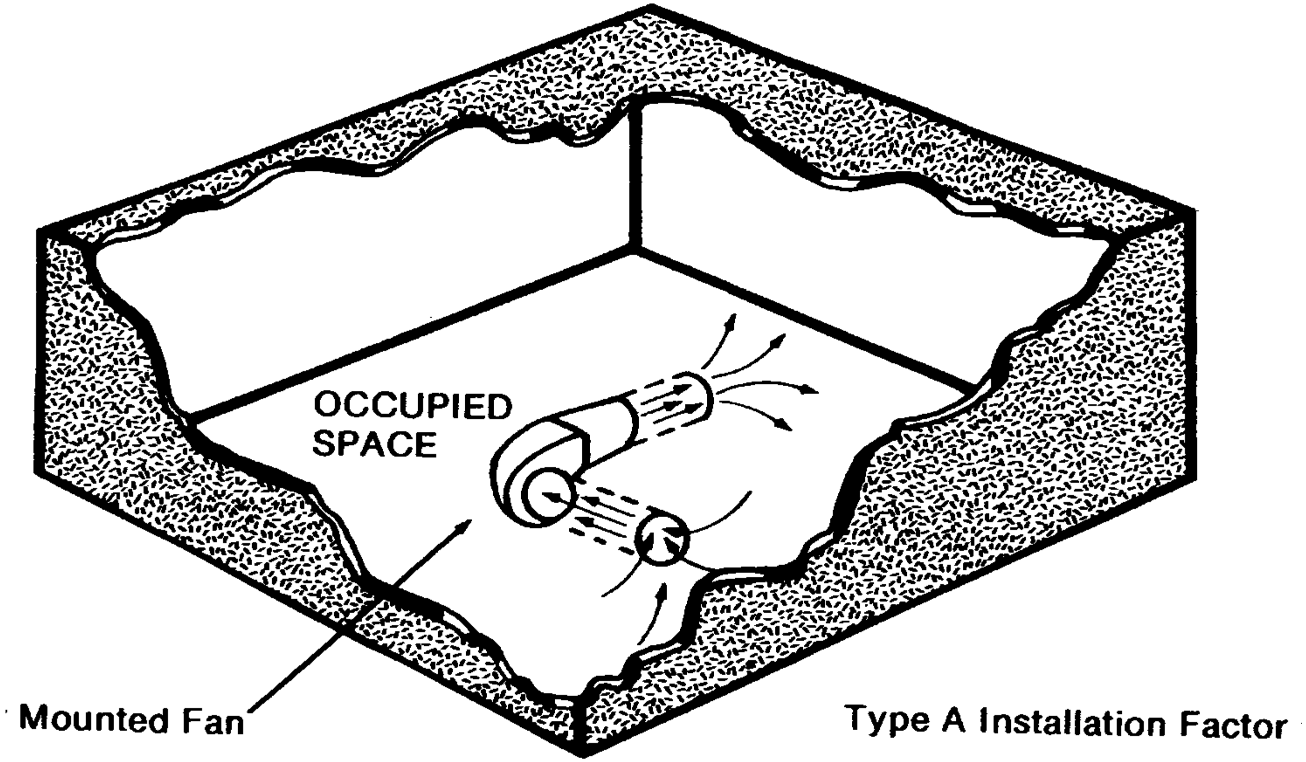
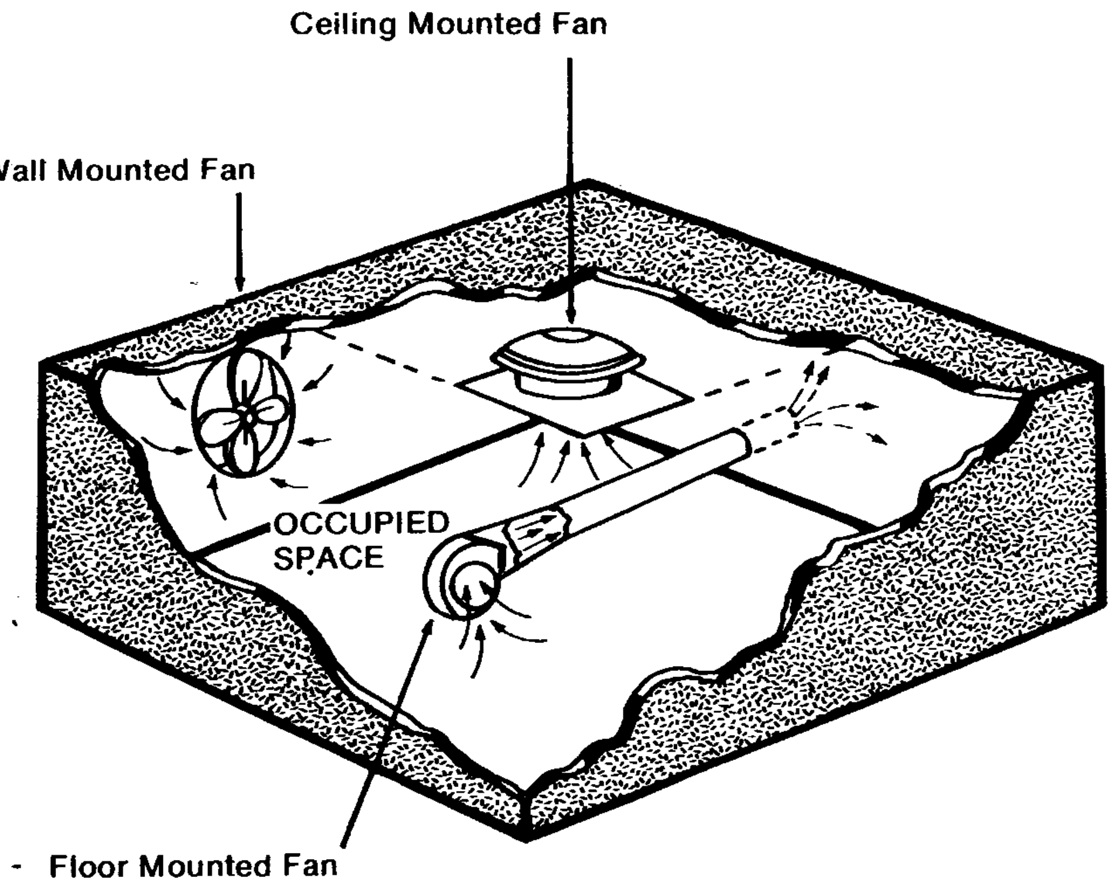


FIGURE 3

Installation Type B



Type B Installation = -3dB for ducted fans
= 0dB for non-ducted fans

FIGURE 4

Installation Type C

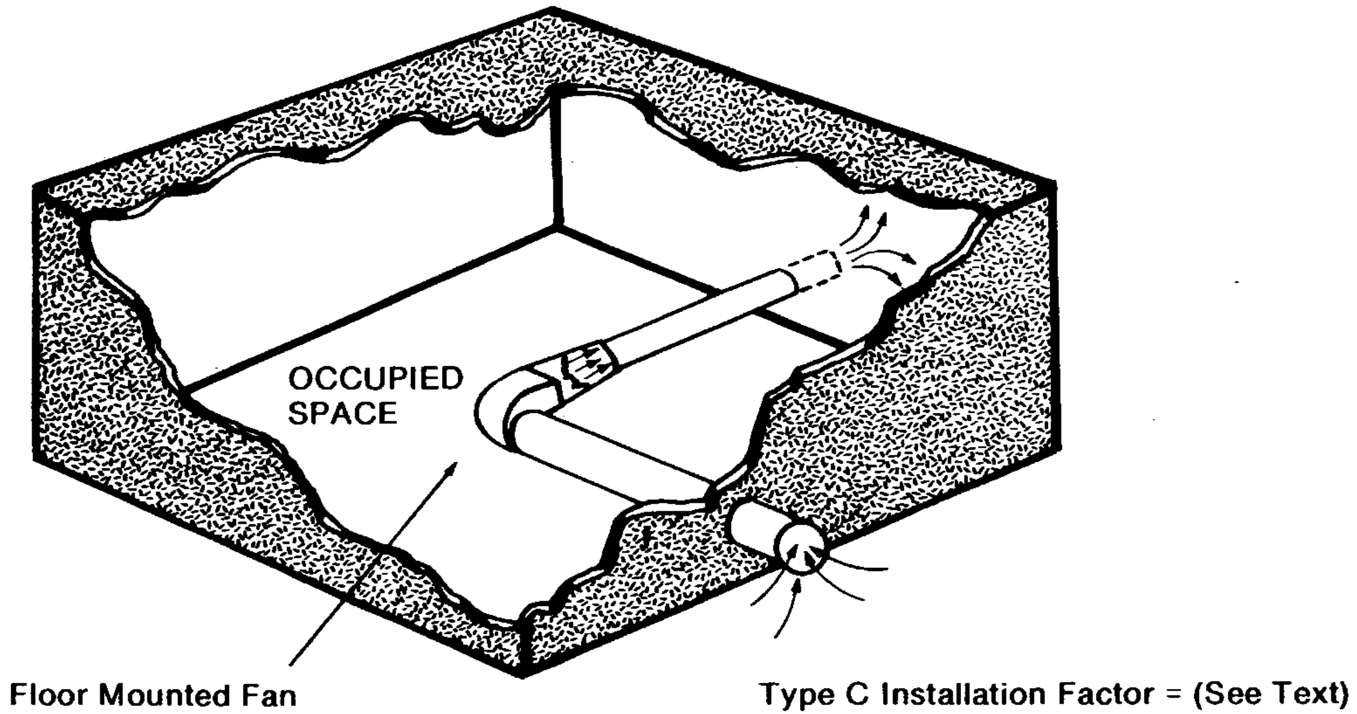
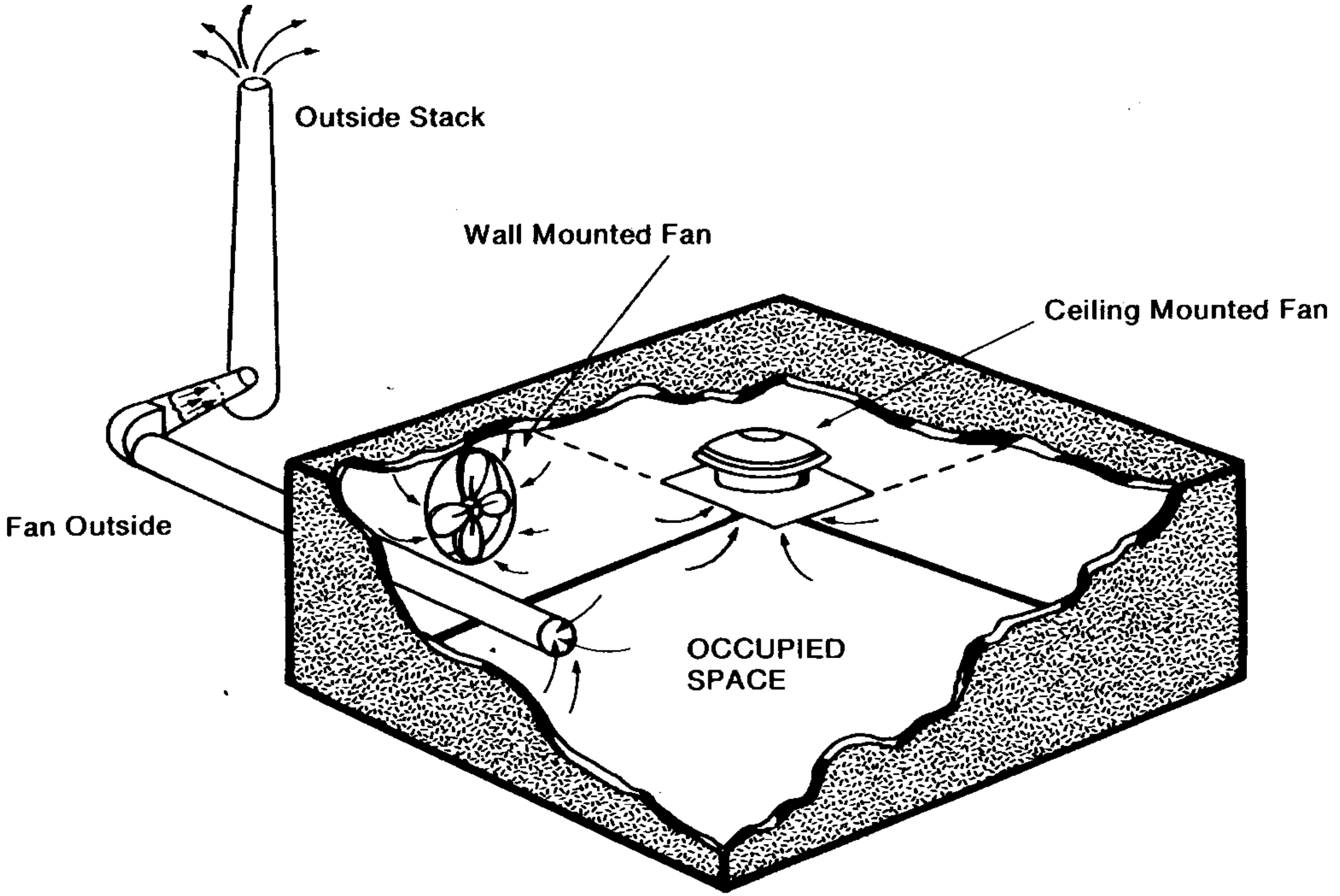


FIGURE 5

Installation Type D



Type D Installation Factor = -3dB for ducted fans
= 0dB for non-ducted fans

FIGURE 6

Estimating Sound Pressure from Sound Power

- Equation for estimating sound pressure levels (ref AMCA 303)

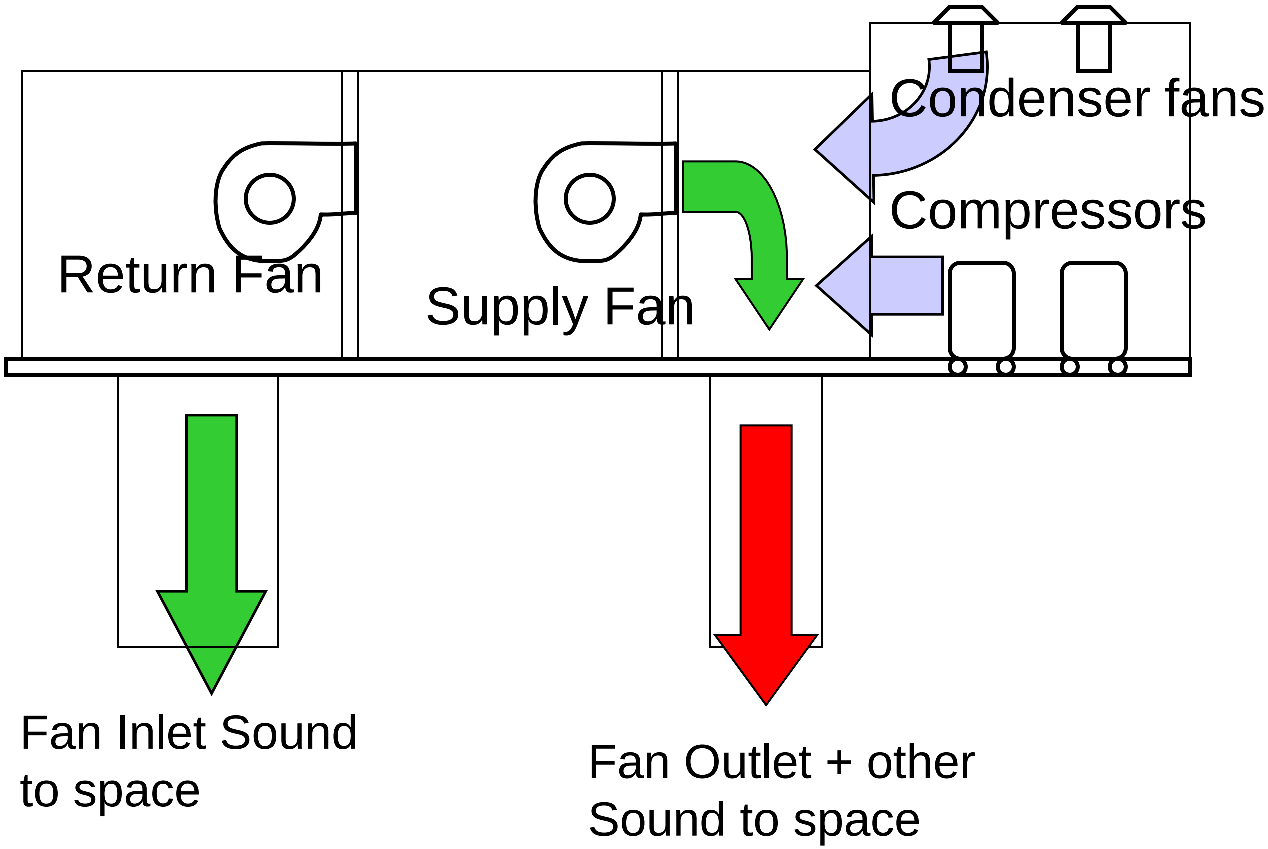
  $$Lp = Lw - 10 \log10 [\ 1/(Q / 4\pi r^2) + 4 / R)\ ] + 10.5$$

  Where:
  - Lp = Sound pressure
  - Lw = Sound power
  - Q = Directivity factor
  - r = Radius in feet from source
  - S = Surface area
  - R = Room construction = S $\alpha \div 1 - \alpha$
  - α = Average sabine absorption coefficient

Sound Pressure is NOT Guaranteed

- Sound pressure levels (dBA) are NOT guaranteed due to several uncertainties
- Customer needs to provide values for “Q” and “r”
  - Q = Directivity factor (based on number of reflective surfaces)
  - r = Distance from sound source
- The actual sound pressure will depend on many factors of the installed environment which cannot be predicted
- Even acousticians will not guarantee the Sound Pressure predicted from Sound Power

Sound Sources



Noise Problems

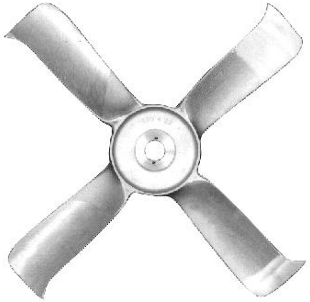
- Two types of noise problems:
  - Those that we anticipate from our sound ratings
  - Those emanating from some abnormal condition
- Cures for noise anticipated from sound ratings:
  - Select a different fan (tip: select lower RPM fans)
  - Relocate the fan to where the noise is not a problem
  - Add vibration isolators and/or flexible connectors
  - Insulate or acoustically enclose the fan
  - Add silencers or duct lining to the inlet and/or discharge

Noise Problems

- Common sources of abnormal or unanticipated noise:
  - Fan wheel unbalance
  - Resonance of fan or attached components
  - Rotating components rubbing on stationary parts
  - Failing, misaligned, or contaminated bearings (on fan or motor)
  - Air leakage - can allow sound leakage and also generate a ‘whistle’
  - Belts slipping
  - Coupling misalignment
  - Motor noise, especially with improper power supply and inverter drives
  - Air turbulence
  - Operation in surge
  - Loose components
  - High velocity air blowing over fixed components which are not part of the fan

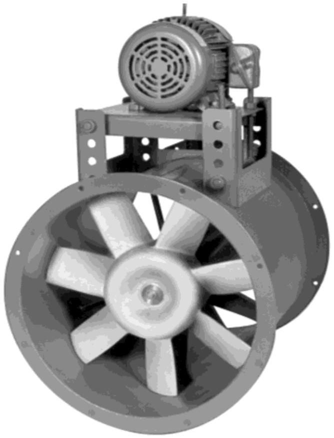
Blade Pass Frequency

- A pure tone produced when the blades of the fan wheel (impeller) rotate past a stationary object (housing cut-off in centrifugal fans, turning vanes in axial fans, or a structural member)
- Calculation: (Number of blades x fan RPM) / 60 Hz
- If blade pass frequency matches the natural frequency of the ductwork it can excite the ductwork
- This phenomena is called resonance, which will increase the noise level



Blade Pass Frequency - Example

- Size 24B7 TCTA tubeaxial fan (7 blades)
- 9,000 CFM, 1.5" SP, 1939 RPM
- BPF = (1939 RPM x 7 blades) / 60 = **226 Hz**
  - 226 Hz BPF falls into the 3rd octave band
  - BPF causes 3rd band to have highest sound level (94 dB)

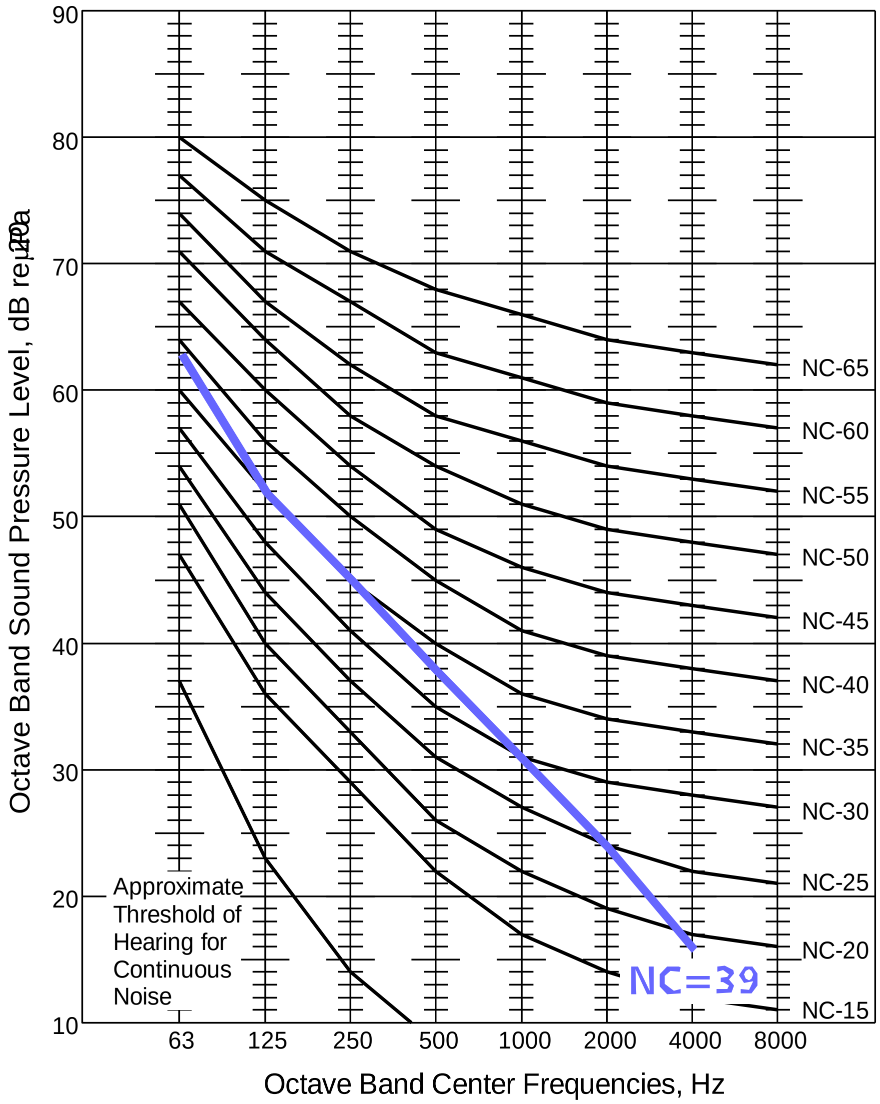


Octave Bands	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Level at Inlet	91	92	94	93	90	82	77	74
Frequency Range (Hz)	45 to 90	90 to 180	180 to 355	355 to 700	710 to 1400	1400 to 2800	2800 to 4600	5600 to 11200
Center Frequency (Hz)	63	125	250	500	1000	2000	4000	8000

Sound Power Level in dB ref 10^{-12} watts

Noise Criterion Curves (NC)

- One method for specifying limits for sound in enclosed spaces
- Developed in 1957
- Typical specification: NC-45

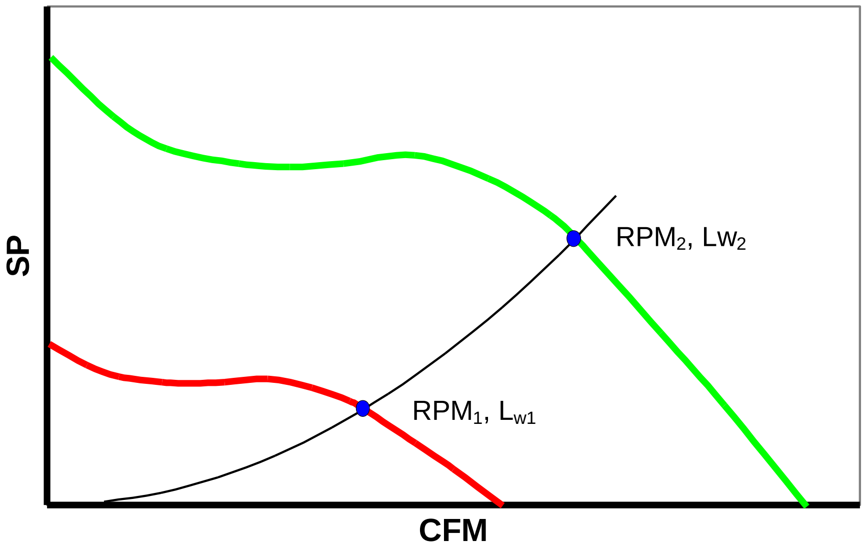


Noise Control Methods

- Source ⇒ often most cost effective but must be considered as part of the whole
- Path ⇒ adds cost to product, examples are:
  - plenum
  - Silencer - This reduction of sound is also referred to as “dynamic insertion loss”
  - barriers or enclosures (better unit casing, duct walls, and/or MER walls)
  - vibration isolators, etc.
- Receiver ⇒ least effective, less likely to be accepted by others, not usually within our control

Fan Laws for Sound

- Apply if fans are geometrically similar
- $Lw_2 = Lw_1 + 50*\log_{10}(RPM_2/RPM_1)$
- Empirical: Sound Power ~ (fan tip velocity)^n
  - FC fan example: n = 4.6 ~ 6.5 BPF; n = 4 ~ 6.5 Broadband
- Used for estimating sound at different speeds along a constant system curve
- Rule of thumb: 10% speed change equals 2 dB

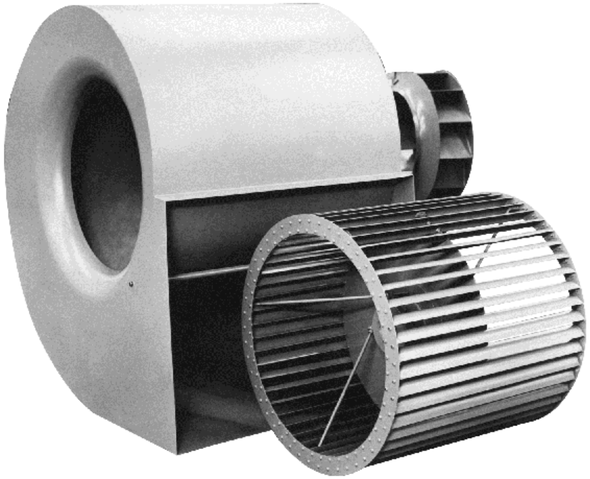


Sound Characteristics by Fan Type

- Airfoil & backward inclined fans
  - Louder than forward curve fans at mid and high frequency
  - More sensitive to inlet flow distortions including inlet guide vanes
  - Significant blade pass frequency tone
  - Narrower useful operating range (when compared to FC) with a ‘soft’ stall onset
  - Usually has less low frequency rumble

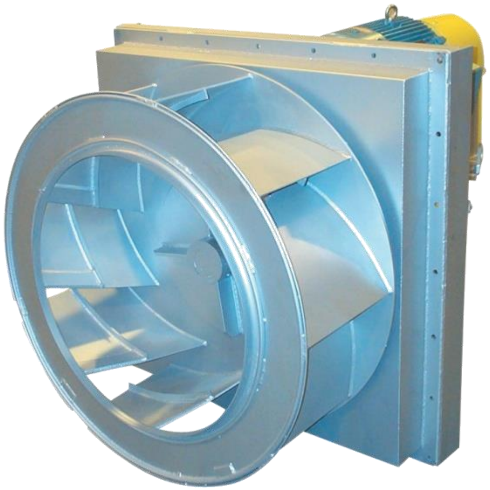
Sound Characteristics by Fan Type

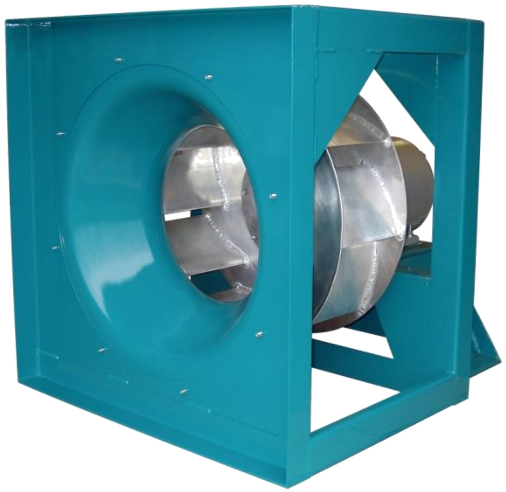
- Forward curved fans
  - Relatively insensitive to inlet flow distortions including inlet guide vanes
  - Wide operating range with a sharp stall onset
  - No significant blade pass frequency tone amplitude
  - Rumble at 31 and 63 Hz bands is common in applications
  - Fan aspect ratio, staggering fan blades, fan cutoff spacing, spiral extension of the scroll all affect the sound



Sound Characteristics by Fan Type

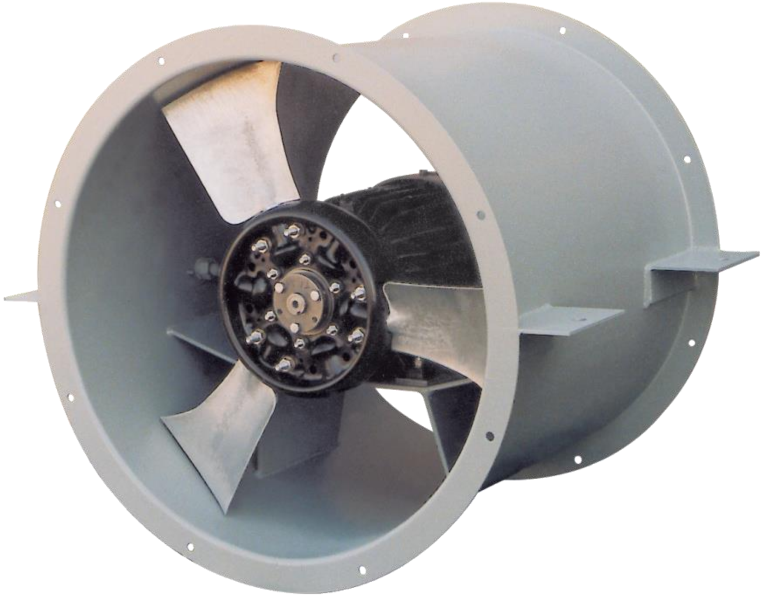
- Plug fans
  - Less turbulence and lower pressure fluctuations entering the discharge duct than housed airfoil and backward inclined fans
  - Generally require more power than housed centrifugal fans and generate higher sound levels, especially at lower frequencies
  - Other characteristics are similar to conventional housed centrifugal





Sound Characteristics by Fan Type

- Vane Axial fans
  - Lowest amplitude at low frequency of any fan type
  - Higher amplitudes at high frequency-can be easily attenuated
  - Most sensitive fan type to inlet flow obstructions
  - Blade pass frequency tone is relatively high amplitude
  - Sharply defined stall region with greatly increased amplitudes



Reminder: Sample selection! Table below will change based on different operating point

All fans selected at peak SE (Static Efficiency) for Airflow=10,000 cfm, Static Pressure (SP)~2 iwc

	Type	Dia (in)	Spd (rpm)	BHP	SE % (Static Efficiency)	LwiA (Inlet Sound Power 'A')
1	Forward Curved- SW (Centrifugal)	30	476	5.09	61.7	89
2	Backward Airfoil – SW (Centrifugal)	36.5	650	3.82	80.0	77
3	Plenum	33	800	4.25	74.0	80
4	Tubular Mixed Flow	27	1074	4.48	70.2	81
5	Tubular Vane Axial	28	1438	4.77	65.9	86
6	Propeller (Axial)	30	1998	4.92	54.4	103

Reference Materials

- AMCA Publications 300, 301, 303
- Twin City Fan ED-300, Fan Sound & Sound Ratings
- Twin City Fan ED-3500, Topics in Acoustics
- Web site: http://www.twincityfan.com/TCFCorporate/TCF/literature.htm

End