NUMBER 7
Computer-Aided HVAC
Acoustical Analysis—Part 1

Acoustical Engineering Report

McGill AirSilence LLC
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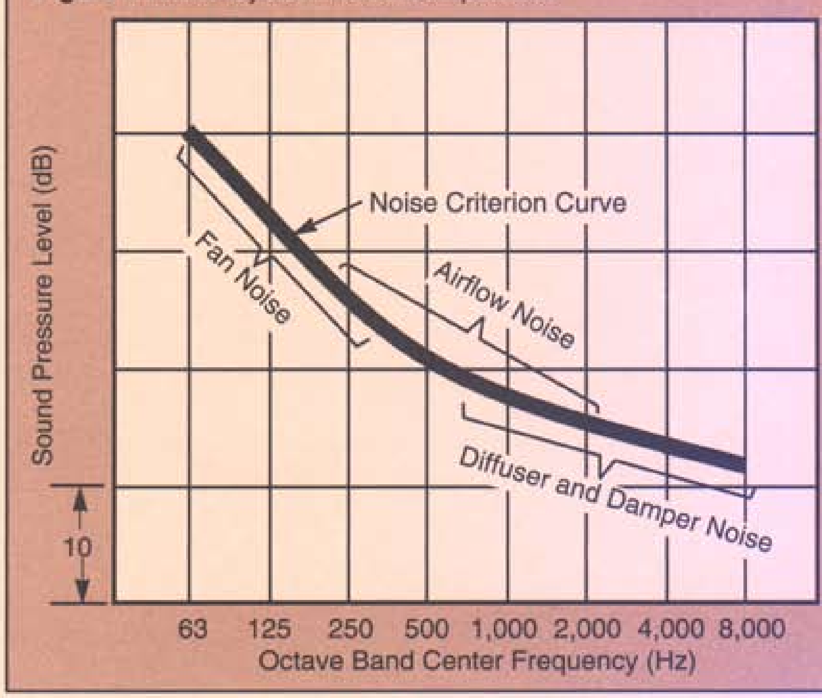
Design Fundamentals

Introduction

An HVAC system should be designed to provide a comfortable (properly tuned) acoustical environment, not to achieve the lowest possible sound level in the critical space. Specifying noise treatment to reduce sound levels as low as possible will result in an improperly designed system with unnecessarily high noise treatment costs. Instead, you should set specific acoustical requirements and analyze the duct system design to determine how much unwanted acoustical energy (noise) the system will produce. A correctly performed acoustical analysis will indicate exactly how much noise treatment is needed to provide a comfortably quiet system with the lowest possible initial cost. Analyzing HVAC system acoustics requires an understanding of the noise sources and attenuation within the system.

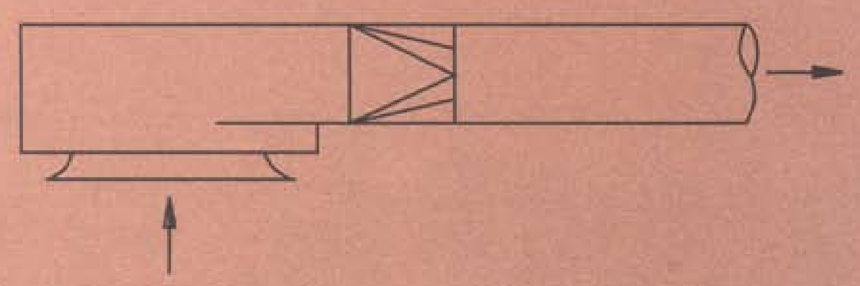
Figure 1 HVAC System Noise Components



Noise Sources

HVAC noise reaching a critical space consists of fan noise (low frequency), duct system component airflow noise (mid frequency), and damper/diffuser noise (high frequency). **Figure 1** shows how these types of noise are distributed across frequency octave bands. Manufacturers of system components publish sound power level values for their products. When not available, these values can sometimes be estimated using methods introduced in Chapter 42, "Sound and Vibration Control," of the 1991 ASHRAE *HVAC Applications* handbook.

Figure 2 Fan System for Example 1



Fans

The primary noise source in an HVAC system is the fan. Fan manufacturers publish fan sound power level (Lw) values that are determined by using Air Movement and Control Association (AMCA) test standards. AMCA test procedures are based on ideal inlet and discharge conditions. Real life variations from these ideal conditions will increase the fan noise levels. When using a fan manufacturer's data, you must distinguish between total fan sound power levels and ducted fan sound power levels. Total fan Lw values include noise radiated by the fan inlet, discharge, motor, drive train, and casing. Ducted fan Lw values represent noise that propagates into the duct system. To perform an acoustical analysis of a duct system, you should use ducted fan Lw values. If the manufacturer cannot supply ducted fan Lw values, estimate them by subtracting 3 decibels (dB) from each octave band of the total fan Lw values.

When consulting a fan manufacturer, take the following steps:

1. Determine if the manufacturer is providing total or ducted fan Lw values.
2. Determine the fan manufacturer's installation recommendations.
3. Determine the fan manufacturer's potential fan choice. Since AMCA standards allow fans to be tested at their peak operating efficiency, the manufacturer's data might be based on peak efficiency. If an installed fan operates far from its peak efficiency, it will be much louder than expected.

Engineers should obtain fan Lw data from the manufacturer whenever possible. When this data is not readily obtainable, it can be estimated using ASHRAE's estimating scheme. Although this scheme is based on data from fan manufacturers, it is not as accurate as the actual manufacturer's data. **Example 1** shows the proper use of ASHRAE's fan Lw estimating scheme.

There are a few important items to consider when controlling the amount of noise generated by a fan:

1. Design the duct system with a computer program that uses the static regain method enhanced by the total pressure design method to achieve the lowest possible operating pressure. Fan noise increases by 20 Log_{10} P, where **P** is the operating pressure of the system.
2. Select the fan to operate near its maximum efficiency. Fans that are oversized and operate at lower than design speed or fans that are undersized and operate above design speed will be noisier.

Noise propagates regardless of airflow direction. When analyzing a duct system's acoustics, evaluate both the supply and return air systems. Remember, the fan is a common noise source for the entire supply and return duct system (see **Figure 3**).

Silencers

Noise generated by silencers is often unaccounted for in a duct system acoustical analysis. There are three common types of duct silencers: rectangular silencers with internal sound-absorbing baffles, round silencers with internal sound-absorbing bullets, and round silencers with no internal baffles or bullets. Baffles and bullets obstruct the flow of air by reducing the open area inside the silencer. As air expands downstream of the silencer, it creates turbulence and generates noise. If the generated noise is within 10 dB of the attenuated Lw values, the two noise levels must be logarithmically combined. **Example 2** calculates

Example 1:
Use the ASHRAE estimating scheme to determine the sound power levels of a fan (see **Figure 2**) that operates under the following conditions.

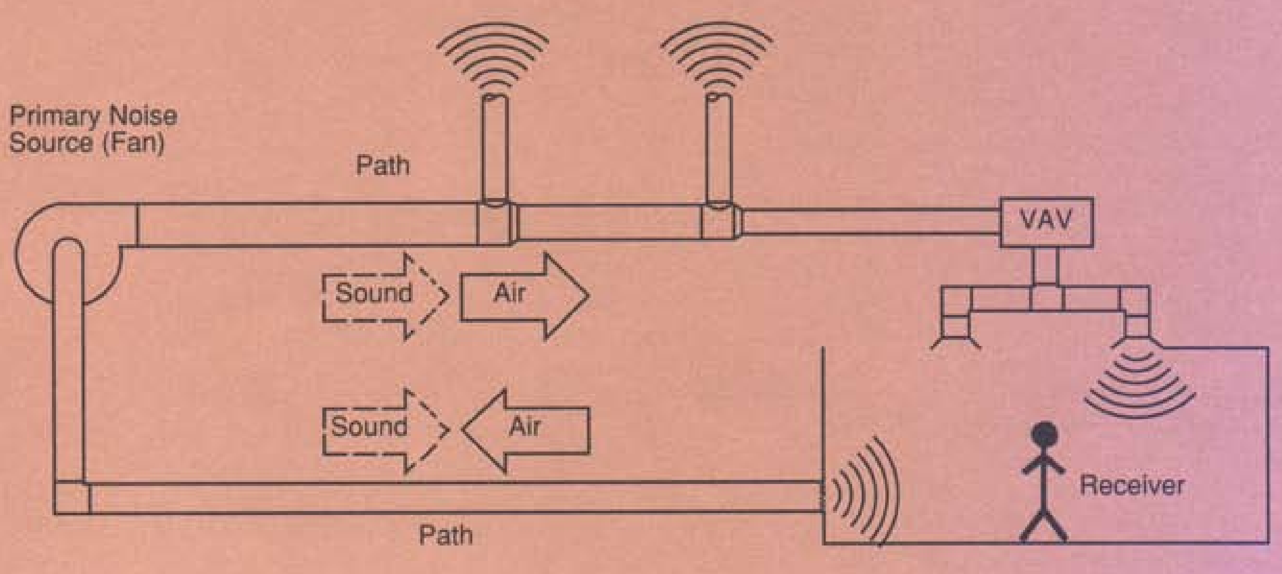
1. Centrifugal airfoil blade fan (24-inch blade)
2. Ducted outlet at 2,979 feet per minute
3. Flow rate = 6,500 cubic feet per minute
4. Fan outlet total pressure = 1.47 inches wg
5. Fan peak efficiency = 78 percent
6. Fan operating efficiency = 72 percent

ASHRAE Equation: $Lw = Kw + 10 \, Log_{10} (Q) + 20 \, Log_{10} (P) + C + BFI$

Solution	Octave Band							
	1	2	3	4	5	6	7	8
1. Kw = Specific fan Lw values[1]	45	45	43	39	34	28	24	19
2. $10 \, Log_{10} \, Q$ = Airflow correction	38	38	38	38	38	38	38	38
3. $20 \, Log_{10} \, P$ = Pressure correction	3	3	3	3	3	3	3	3
4. C = Percent of peak efficiency[2]	3	3	3	3	3	3	3	3
5. BFI = Blade frequency increment[3]	—	—	3	—	—	—	—	—
6. Estimated fan Lw values	89	89	90	83	78	72	68	63

[1] *HVAC Applications*, ASHRAE, 1991, p. 42.8, Table 4.
[2] *HVAC Applications*, ASHRAE, 1991, p. 42.10, Table 7.
[3] *HVAC Applications*, ASHRAE, 1991, p. 42.9, Table 5.

Figure 3 Supply and Return Air Systems



Example 2:
Calculate the noise downstream of a silencer, using the estimated fan Lw values calculated in Example 1.

Solution	Octave Band							
	1	2	3	4	5	6	7	8
1. Fan Lw_{IN}	89	89	90	83	78	72	68	63
2. Silencer insertion loss	-4	-7	-19	-33	-38	-38	-29	-24
3. Lw1	85	82	71	50	40	34	39	39
4. Silencer generated noise level (GNL) at 3,000 fpm	70	64	60	62	61	62	59	52
5. Lw2	85	82	71	62	61	62	59	52
Error if silencer GNL is not accounted for (Lw2 - Lw1)	0	0	0	12	21	28	20	13

the noise downstream of a silencer and shows the error introduced if the noise generated by the silencer is not considered in the acoustical analysis.

Balancing Dampers

The noise generated by dampers is a function of the air speed flowing past the damper. At high velocities, which are common in poorly balanced systems, excessive noise is generated. One solution is locating the dampers a sufficient distance upstream of the outlet diffuser or grille. This will allow the duct to remove enough noise to meet a specified criterion. Another solution is to design the system using the static regain design method enhanced by the total pressure design method. This will result in a well balanced system that does not require dampers.

Diffusers and Grilles

Air flowing through diffusers or grilles generates turbulence. Again, more noise is generated at higher velocities. This noise is critical because it is the last noise source that affects the sound levels in the critical space. Manufacturers of such devices publish Lw data with reference to noise criteria (NC) levels.

Duct Elements

Air generates noise as it flows through duct system components such as duct, elbows with or without turning vanes, tees, and crosses. This noise generation is a function of flow velocity, duct size, number of vanes, radius of the bend or elbow associated with the turn or junction, and the location of dampers, elbows or branch takeoffs upstream of the turn or junction being examined. Refer to the ASHRAE *Algorithms for HVAC Acoustics* manual for further information.

Natural Attenuation

For an acoustical analysis to determine how much noise control an HVAC system needs, it should take into account the natural attenuation of the system components. Natural attenuation is a function of energy losses due to duct vibration, sound reflection due to elbows and duct outlets, and energy division due to divided-flow fittings. Including natural attenuation in an acoustical design can reduce or eliminate the need for expensive, energy-consuming supplemental attenuation. The following paragraphs discuss the major sources of natural attenuation.

Single-Wall Duct

As sound waves travel through a duct system, some sound energy is transmitted to the surrounding duct surface (see **Figure 4**). This energy transfer reduces the amount of sound energy traveling through the duct toward the critical space. In long runs of duct, a significant amount of noise can be attenuated. This attenuation is expressed in decibels per foot (dB/ft) and is a function of duct shape and size. To calculate, use the diameter for round duct and the minor axis for flat oval duct.

Elbows

When sound waves enter a sheet metal elbow, a portion of the wave energy is reflected (see **Figure 5**). Reflection reduces the amount of sound energy available to propagate beyond the elbow. This attenuation is expressed in decibels per elbow. For elbows with angles less than 90°, the

Figure 4 Sound Transmission in Single-Wall Duct

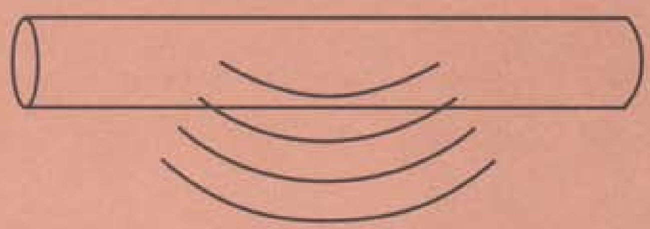


Figure 5 Sound Reflection in Elbows

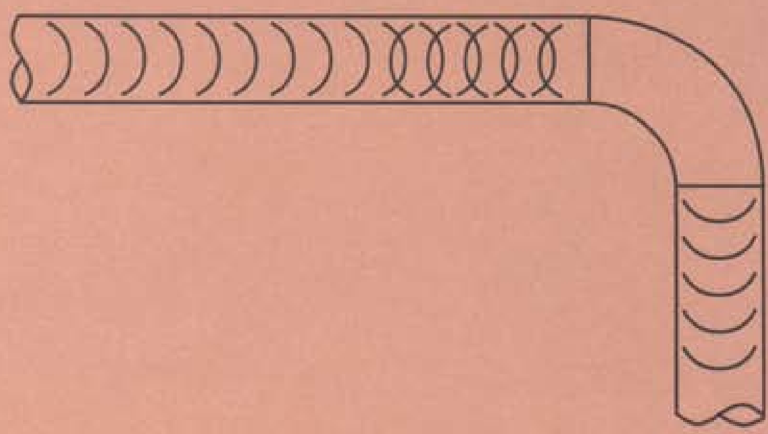


Figure 6 Power Splits in Divided-Flow Fittings

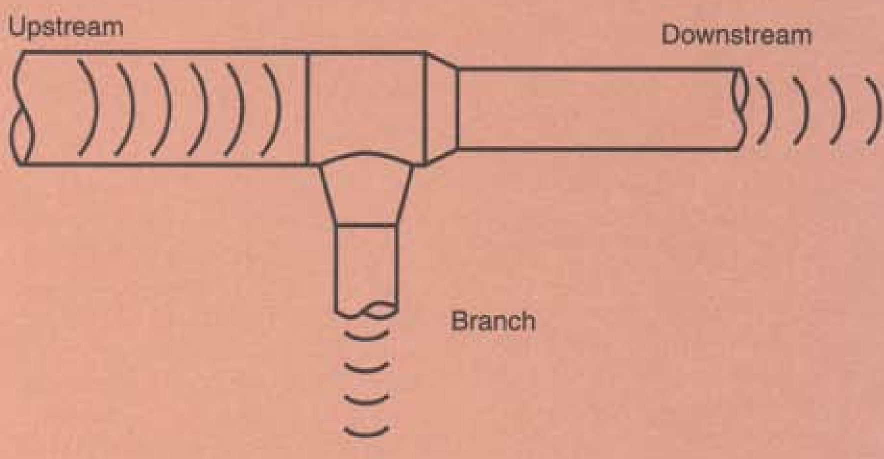
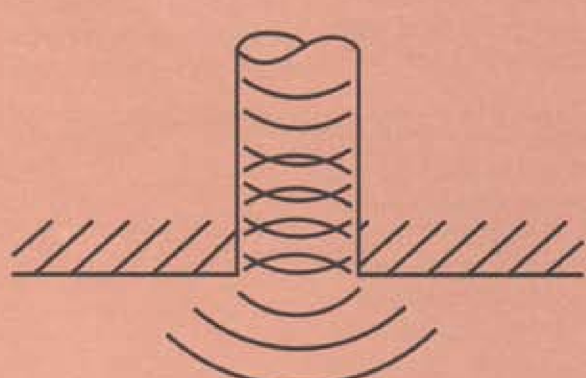


Figure 7 End Reflection in Duct



attenuation is proportional to the actual bend of the angle divided by 90°. To calculate, use the diameter for round elbows and the minor axis for flat oval elbows.

Power Splits

Power splits are the most significant natural attenuation source. Sound energy, like air, splits at a divided-flow fitting (see **Figure 6**). This energy division is proportional to the cross-sectional areas of all downstream flow paths at a particular junction. Attenuation due to a sound power split applies to all frequencies. Knowledge of sound power splits can be used constructively when a system includes plenums. Replacing a run of large-aspect-ratio rectangular or flat oval duct with several runs of round duct increases the noise control.

End Reflection

When there is a significant change of area at the end of a duct run, low frequency acoustical energy is reflected into the duct (see **Figure 7**). This change of area occurs when a duct discharges air directly into an open space. The end reflection effect is virtually negated when a variable air volume (VAV) box, diffuser, or register is placed at the duct opening.

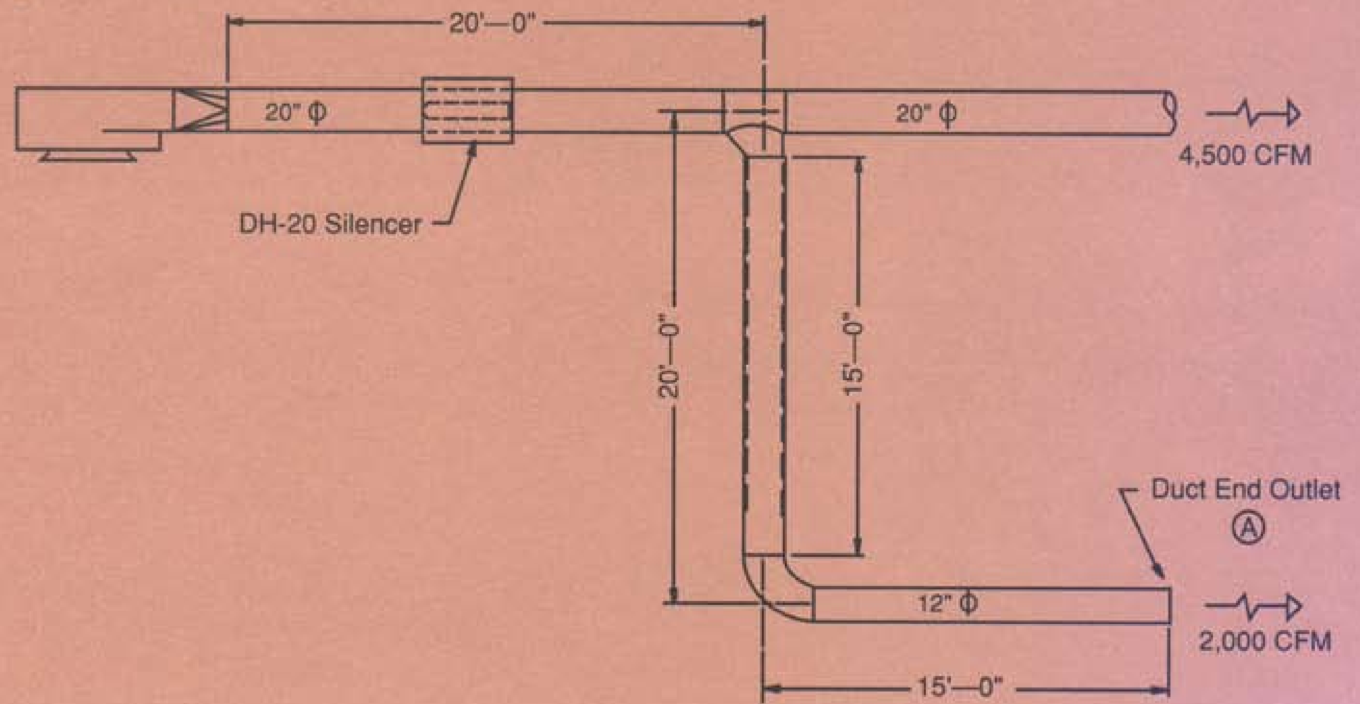
Supplemental Attenuation

When natural attenuation is not enough to solve a noise problem, supplemental attenuation is needed. This attenuation can be provided by lined duct, double-wall duct, or duct silencers. Lined duct or double-wall duct can be used throughout a duct system to attenuate fan noise. It can also be used upstream of terminals or diffusers if a problem is expected at a particular outlet location.

Lined Duct

An effective way to reduce noise in a duct system is to use lined duct. Rectangular lined duct is constructed of a solid outer shell with a layer of insulation attached to the inside of the duct. A coating can be applied to prevent airflow from eroding the insulation. Rectangular lined duct performance data (dB/ft) is listed as a function of duct size in

Figure 8 Duct System for Example 3



Chapter 42 of the 1991 ASHRAE *HVAC Applications* handbook.

Double-Wall Duct

United McGill's ACOUSTI-k27® duct and fittings are constructed of a solid outer shell and a perforated inner shell with a 1-, 2-, or 3-inch layer of insulation enclosed between the shells. Data (dB/ft) is published in United McGill's Engineering Report Number 131, *ACOUSTI-k27® Double-Wall Duct*. The performance of ACOUSTI-k27® duct is a function of diameter, insulation thickness, and airflow velocity. With flat oval duct, use the minor axis dimension for calculations. Rectangular-k27® duct is also available; it performs comparably with ASHRAE data for rectangular duct with a 2-inch liner.

Baffle/Bullet Silencers

Silencers with internal baffles or bullets are often placed downstream of a fan to attenuate duct-borne noise. Their attenuating performance is measured in terms of insertion loss. Insertion loss is the change in sound pressure level at a specified location when a sound attenuating device is placed between the sound source and the measurement location. The standard measurement procedure is ASTM E477, Standard Method of Testing Duct Liner Materials and Prefabricated Silencers for Acoustical and Airflow Performance. Silencers can be purchased with varying percent open areas, depending on the type of noise control desired and the allowable pressure drop.

No-Loss™ Silencers

No-Loss™ silencers provide attenuation similar to the baffle/bullet silencers. However, they have no baffles or bullets and introduce no additional pressure drop into a duct system. These silencers get their attenuation from insulation within a double-wall construction, and they can provide a high degree of low frequency noise control.

Acoustical Analysis

To perform an acoustical analysis of a duct system, use the method shown in **Example 3**.

Using the outlet sound power levels derived in **Example 3** and in **Figure 1** from United McGill's Acoustical Engineering Report Number 6, *Qualitative Analysis: Establishing Acoustical Design Goals*, the result is an NC of 45.

Conclusion

Performing an acoustical analysis of a duct system involves many variables. When dealing with large systems, this process can become long and tedious. You can save valuable time by using United McGill's UNI-DUCT® computer-aided duct system design program to acoustically analyze systems and solve potential noise problems before they occur. This computer program also enables you to quickly analyze the effects of various noise control solutions for the same noise problem (this process will be discussed in Acoustical Engineering Report Number 8). Computer-aided acoustical analysis enables you to provide the best noise control solutions at the lowest initial cost.

Example 3:
Determine the noise level at Outlet A of the system shown in **Figure 8**.

Solution	Octave Band							
	1	2	3	4	5	6	7	8
1. Estimated fan Lw values	89	89	90	83	78	72	68	63
2. Insertion loss DH-20 at 2,979 fpm	-4	-7	-19	-33	-38	-38	-29	-24
3. Bare duct attenuation	-3	-2	-1	-1	-1	-1	-1	-1
4. Resultant 1	82	80	70	49	39	33	38	38
5. DH-20 GNL at 2,979 fpm	70	64	60	62	61	62	59	52
6. Duct GNL 20" at 2,979 fpm	64	59	54	49	51	50	40	40
7. Resultant 2	82	80	70	62	61	62	59	52
8. Power split	-6	-6	-6	-6	-6	-6	-6	-6
9. Resultant 3	76	74	64	56	55	56	53	46
10. Fitting GNL	74	71	67	63	57	50	43	35
11. Resultant 4	78	76	69	64	59	57	53	46
12. Bare duct attenuation	-5	-5	-4	-2	-2	-2	-2	-2
13. Elbow attenuation	0	0	0	-1	-2	-3	-3	-3
14. 2-inch k27® duct 15 feet	-4	-9	-16	-29	-29	-24	-20	-18
15. Resultant 5	69	62	52	32	23	28	28	29
16. Duct GNL	56	47	45	44	45	42	34	34
17. Elbow GNL	31	32	31	30	27	24	19	14
18. Resultant 6	69	62	53	44	45	42	35	35
19. End reflection	-4	-1	0	0	0	0	0	0
20. Lw_{OUT}	65	61	53	44	45	42	35	35

References:

1. Engineering Report Number 131, *Acousti-k27® Double-Wall Duct*, United McGill Corporation.
2. Engineering Report Number 136, *Generated Self Noise of Lined Duct*, United McGill Corporation.
3. *Algorithms for HVAC Acoustics*, ASHRAE, 1991.
4. *HVAC Applications*, Chapter 42, "Sound and Vibration Control," ASHRAE 1991.
5. *Noise Control for Buildings and Manufacturing Plants*, Bolt, Beranek and Newman, Inc., 1989.

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