Building Quiet Wind Systems

David W. Kahn

David Kahn is an acoustics consultant specializing in performance space design. Prior to establishing Acoustic Dimensions, he was employed by Artec Consultants. Some of David's recent projects include an 1,800-seat concert hall/chapel at Bethel College in Minnesota (while employed at Artec), and All Souls Unitarian Church in New York City. He also performs as a trumpeter with the New York Symphonic Arts Ensemble.

Cover illustration: The 11 Noise Criteria (NC) curves used to quantify background noise levels in indoor spaces. A standard threshold of hearing curve is also shown.

Organs are usually placed in worship spaces and often in concert halls or other types of performance spaces such as recital halls and school auditoriums. All of these spaces are considered to be acoustically critical. While organbuilders might think of sound dispersion and reverberation characteristics as the most important acoustical factors, I believe that we must also design worship and performance spaces to be as quiet as possible.

Benefits of Reducing Noise

The importance of silence for good acoustics is often underestimated. In my experience, a very quiet space can have a tremendous impact on one's perception of the acoustics. An extremely quiet space can improve one's perception of the acoustical intimacy and clarity. The subjective reverberation time—that is, the time it takes sound to die away to inaudibility—is lengthened in a very quiet room. Extreme quiet can add to the drama and intensity of a worship service or concert performance. The spoken word becomes much easier to understand, especially in situations involving untrained speakers or inadequate PA systems. A very quiet room provides musicians with greater freedom to play softly, thereby increasing the available range of dynamics. Extreme quiet can create great tension and excitement during soft passages or pauses in music. I am convinced that extreme quiet is an important ingredient in the magic of great acoustics and memorable performances.

One of the projects I worked on in the recent past was the new Meyerson Symphony Center in Dallas. One of my major responsibilities on that project was making sure the hall was quiet. By some miracle, considering the construction pace and the number of unfinished items outstanding at opening week, the room was in fact extremely quiet for the opening week's concerts. The extreme quiet in the hall did not go unnoticed by the performing musicians. Among the highlights of that week was a performance by the Kronos String Quartet, a contemporary ensemble. One of their pieces ended with the cellist lightly plucking a string softer and softer, fading out to inaudibility. The entire audience literally held their breath, sitting at the edge of their seats until the softest touch to the string faded out. It was one of those memorable moments I will never forget, and one that never would have occurred had there been any audible noise in the hall. Many of the critics also picked up on the extremely low background noise level in the hall, writing about the "breathtaking clarity" of the softer passages and audiences that were "pin-drop quiet."

Measuring Background Noise

Acousticians have developed a number of ratings systems for quantifying noise levels for indoor spaces. The most common system (although not necessarily the most appropriate one) is a system of curves called *Noise Criteria* (NC) *Curves.* As seen in the cover illustration, an NC curve is formed by plotting eight sound level measurements taken at one-octave intervals beginning at 63 **Hz** and continuing to 8,000 **Hz.** The cover graph shows the eleven standard "bench mark" curves defining NC levels from a low of NC-15 (an extremely quiet room) to a high of NC-65 (the noise level of a typical crowded restaurant). The background noise level of a typical office would be NC-35. To determine a room's NC level, one would measure its sound level in decibels at each of the specified octave-band frequencies and plot these values on the chart. The resulting curve is assigned the NC rating of the closest standard curve that does not dip below any point of the room's curve.

A number of engineering groups have developed recommended background noise levels for various types of spaces. Concert halls and worship spaces are normally recommended to have very low background noise levels not exceeding NC-15 (the lowest defined curve) or NC-20. In my opinion, even the NC-15 rating represents a significant compromise to acoustical quality. I believe that there should be no audible noise in a very acoustically critical space. The criterion for no audible noise is the threshold of hearing, and the curve used to define this sound level is also included in the cover graph.

Figure 1 shows the background noise levels measured in the Meyerson Concert Hall during opening week with all of the mechanical and electrical systems turned on. You can see that the criterion for inaudibility was not quite met, yet the levels are well below NC-15.

Extreme quiet is also crucial to the success of worship spaces. Another project I worked on a few years ago was the Calvin College Chapel in Grand Rapids, Michigan. Figure **2** shows the background noise level measured in the middle of the chapel with the HVAC system turned on. (HVAC stands for ***Heating, Ventilating and Air-Conditioning.)*** The second curve labeled "organ on" represents the added noise of the organ's wind system. Note that the blower for this organ is located several hundred feet away in a basement mechanical room that is structurally separate from the chapel. Even with this care to reduce blower noise, there is a very substantial increase in noise with the organ turned on.

Noise Reduction Methods

Although the following recommendations for noise reduction are based primarily on my knowledge of designing quiet HVAC systems, many of these techniques can be used quite effectively by the organbuilder in designing a quiet wind system. The major difference in the two applications is that pressurized organ wind normally has little or no velocity, so the organbuilder is spared some of problems with rushing air that the HVAC system designer must face.

The noise produced by the fans used in commercial HVAC systems can be predicted fairly accurately. Actual measured data are frequently available from the manufacturer. Fans for a typical building HVAC system are often ten to twenty times the size of a typical organ blower fan.' HVAC fan noise is usually attenuated by placing acoustical lining in the ductwork, by providing duct silencers which are like mufflers inserted into the ductwork, and by including expansion plenums lined with sound-absorbing materials.

The amount of fan noise attenuation provided by ductwork is very much a function of its size. Smaller ducts always attenuate more sound than bigger ducts. For a typical building HVAC system, this is good news in the sense that smaller ducts are always less expensive and easier to install than bigger ducts. The only problem is that if the duct is too small, the speed of the air traveling through the duct gets to be too fast and the noise of rushing air becomes an issue. The sizing of ductwork therefore becomes a careful balancing act between attenuating as much fan noise as possible without generating too much air flow noise. In the case of an organ wind system, the ductwork should also be sized as small as possible in order to reduce fan noise more effectively. The limiting factor in this case would be the organ blower's inability to deliver full static pressure through an excessively small duct.

The noise of rushing air increases dramatically with increasing air velocity. A doubling in air velocity can result in noise increases of close to 20 decibels, which would be perceived as being almost four times as loud. (An increase in 10 decibels in normally perceived as being twice as loud.) The amount of noise generated by moving air also depends on duct geometry. Sharp turns in the duct—mitered elbows in particular—can generate tremendous noise.

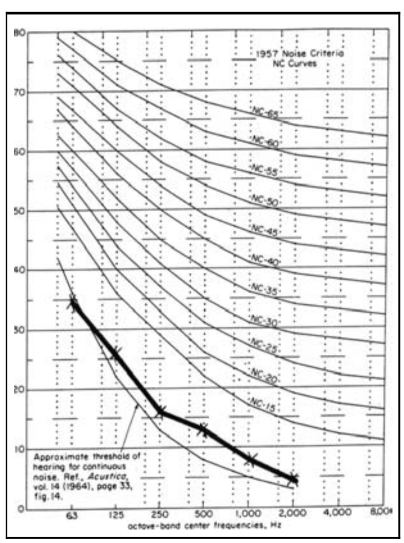
Although the noise of rushing air is not a major problem in organ wind systems, this issue should not be ignored altogether. I recommend that all turns in organ ductwork be radiused and smooth; abrupt transitions and mitered elbows should be avoided. Other sources of air turbulence noise in an organ include leaks in the wind system and any valves or dampers that limit flow. In general, the greater the static pressure in a wind system, the greater such noises can be.

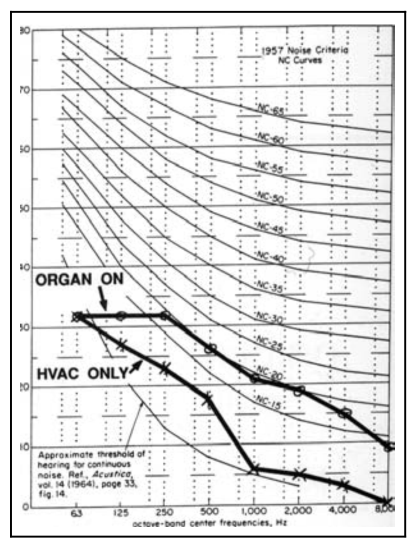
Rectangular vs. Round Ducts

Most of the ductwork one finds in HVAC systems is lined, rectangular sheet-metal ductwork; sometimes it is unlined. The static pressure in typical HVAC systems is usually quite low. When static pressures exceed a water column of *6"* or so in typical HVAC systems, round ducts are substituted for rectangular ducts. Unfortunately, round ductwork has some acoustical disadvantages. Given the

fig. 1 (left): Background noise curve for the Meyerson Symphony Center, plotted just above the threshold of hearing curve.

fig. 2 (right): Background noise curves for the chapel at Calvin College, Grand Rapids.





same cross-sectional area, rectangular ductwork is significantly more effective in attenuating noise (and especially low-frequency noise) than round ductwork. Low-frequency noise is usually the hardest to attenuate in any wind system.

Expansion Plenums

Expansion plenums are perhaps one of the most effective methods of fan noise attenuation, particularly at low frequencies. An expansion plenum is essentially a large air reservoir. The air is fed to and extracted from the plenum by relatively small ducts, so the velocity of the air practically stopped within the plenum before being sped back up in the exit duct. Fortunately, most organs incorporate expansion plenums or reservoirs. For acoustical reasons, organ plenums or reservoirs should be lined with sound-absorbing plenum liner boards.[2] This material is a high-density fiberglass board coated with black neoprene to prevent any delamination of the fiberglass into the airstream. It would also be suitable for lining rectangular wooden wind conductors in an organ.

Prefabricated panels are frequently used for constructing plenums in commercial HVAC systems.[3] The panels consist of four-inch thick glass fiber covered with a perforated sheet metal liner. The glass fiber is wrapped in thin mylar so the fibers cannot get into the airstream. Organbuilders might want to consider this method of constructing an expansion plenum.

The acoustical effectiveness of a plenum is a function of both the acoustical lining and the plenum's design. Volume is a factor, the geometrical relationship between inlet and outlet plays a role, and the size of the plenum outlet is critical. The outlet should be as small as possible—without being so small that excessive static pressure or excessive air velocity is created. The inlet and outlet should always be offset as much as possible, and should be as far away from each other as possible. Regarding the volume, the bigger the better. I recognize that bigger is not always better from the organbuilder's perspective, but a larger plenum does provide steadier air and reduced fan noise. As a rule of thumb, the expansion/contraction ratio should be at least 4:1.

Organ Ductwork

An organ's static pressure frequently exceeds 6″, so rectangular ductwork is often not practical. Round ductwork, being much better suited for very high-pressure systems, is used in most organ installations. Galvanized duct, Orgaflex and PVC pipe are among the commonly used materials. When these ducts are unlined there is almost no sound attenuation at all, and any noise produced by the fan is carried practically unhindered into the organ and then into the room.

Actually, some sound attenuation occurs with unlined rectangular sheet-metal duct because sound can break out of its thin walls. In the case of a wooden rectangular duct, and certainly any round duct, the materials are much stiffer.and therefore little, if any, sound escapes as it travels through the wind system.

If round ductwork is required for high-pressure systems, it can be acoustically lined. One manufacturer of lined round ductwork is United McGill.[4] Another possible alternative would be to use "Rigid Round" preformed duct.[5] This is round fiberglass duct that could be slid inside an existing galvanized wind conductor. In the case of the Fisk organ in the Dallas symphony hall, there are two separate windlines for the low-pressure and high-pressure divisions. Both windlines are quite long runs of acoustically lined duct.

Ducting from Remote Organ Blowers

In organs with remote blower locations, it is best to have an expansion chamber (the static reservoir) close to the blower so that there is a plenum and some length of lined duct to attenuate blower noise before the windline enters the room and the organ. By using lined ductwork made of a thinner-gauge metal, low-frequency noise can break out of the thin duct walls while high frequencies are absorbed by the duct lining. Once the windline enters the room or the organ itself, however, a different approach is required. This is because any noise still remaining must not escape the wind system. The goal is to have as much noise as possible escape from the windline ***before*** it enters the room or the organ.

Flexible Connectors

One noise reduction technique commonly used in both pipe organs and HVAC systems is to place a flexible piece of canvas or neoprene-coated canvas between the blower and the duct or reservoir. This is useful in isolating vibration of the blower from the duct. However, because the material is light and flexible, noise can escape through this connection very easily. For this reason, such connections must not be used in any part of the wind system within the room or the organ. The problem of noise break-out with these canvas connectors is similar for flexible wind conductors such as Orgaflex.

Air Velocity and Turbulence

As mentioned previously, air turbulence is very sensitive to changes in velocity. The velocity of air through ductwork in an organ wind system is, of course, not constant as it is in most HVAC systems. If the ductwork is not running within the performance or worship space, it is permissible to allow maximum velocities of up to 1200 fpm. Higher velocities than this can cause excessive noise and also generate substantial pressure drops due to friction. Once the organ windline is in the room or the organ, I suggest that maximum velocities not exceed 700-800 fpm. This is accomplished by increasing the cross-sectional area of the duct. Even though turbulence noise is not critical when full-organ is being played, it is after releasing a loud chord that silence is important. Air that is rushing at high velocity through the wind system to refill reservoirs can be audible, perhaps even to the point that the apparent decay time is reduced (perceived as a reduction in reverberation time).

It is essential that all turns in the ductwork be gradual. 90° bends should be full-radius bends (i.e., the radius of the bend is no less than the radius of the ductwork). My suggestions for maximum velocities are based on windlines with very smooth turns and transitions. If any abrupt changes or mitered elbows are used (such as those common in wooden windline construction), these velocities would need to be halved to ensure quiet. But here again, enlarging duct size to reduce velocity will result in less effective fan noise attenuation, so this approach is not recommended. The best approach is to use smaller ducts with smooth bends.

Sound-Containing Blower Enclosures

I intentionally did not call this section "soundproof blower enclosures" since there really is no such thing. The enclosure must *contain* sound as much as possible. There is a big difference between sound containment (isolation) and sound absorption or reduction. For example, if you take an extremely effective sound-absorbing material such as fiberglass and wrap it around a blower, it will not contain the noise very well. Sound isolating materials tend to be heavy and stiff. Concrete is certainly a good sound isolating material, but it is not particularly easy to work with. Wood is acceptable, but other materials such as gypsum board (or even better, lead-lined gypsum board) are considerably heavier and therefore more effective sound-isolating materials. Lead-laminated plywood is also available and is quite an effective noise barrier. Lead-lined products are usually available through a local lead supplier. A good sound-containing enclosure must be massive and stiff, but it is also important to line the inside of the enclosure with sound-absorbing materials such as the plenum liner board previously discussed.

Another critical issue regarding the construction of enclosures is that they must be airtight. Sound always finds the easiest means of escape. This means that no matter how heavy and massive an enclosure you build, if there are any holes or leaks, it will not work very well. This presents a problem in our particular case because there must be a way for air to get into the enclosure to feed the blower.

Now we are getting back to the techniques of HVAC noise reduction. The air intake into the enclosure box should be ducted. It's hard to generalize, but this duct must be at least four or five feet long to be effective; I would say that a length greater than twenty feet is probably not required. An appropriate intake duct depends on many factors, but in general, try to follow the guidelines given earlier regarding the use of lined duct that is sized as small as possible without creating excessive velocities or impairing capacity. I usually recommend a round intake duct instead of a rectangular one since sound is more effectively contained by round ductwork.

"Ductwork should be sized as small as possible in order to reduce fan noise more effectively"

Another weak link in sound-containing enclosures is often the access panel or door. Good sound seals around the perimeter are essential. Sponge neoprene is a good material to use. The doors must also have positive latching devices that compress the perimeter seals.

Summary

- Extreme quiet is an important ingredient for good acoustics. Quiet organ wind systems are required to meet this criterion.
- Noise is produced by both the fan itself and by air turbulence.
- Fan noise can be reduced in organ wind systems with many of the same techniques used for quieting commercial HVAC systems. Acoustical lining is recommended in the wind conductors. The wind conductors should be rectangular sheet metal ductwork when static pressures are not too high, and lined round ductwork for high-pressure systems. The reservoirs should also be lined with sound-absorbing materials.
- Air turbulence noise can be reduced by limiting maximum velocities in the wind conductors, and by providing only smooth curves and transitions in the wind system. Mitered elbows should be avoided.
- When it is not possible to place the blower in a remote room, it must be placed in a well-sealed enclosure that is stiff and massive, lined with sound-absorbing material. Air supply to the blower should be through a duct leading into the enclosure.

Notes

1. **Suppliers of organ blowers do not, to my knowledge, provide fan noise data. One could apply the equations used to predict noise generated by large commercial air handling units to organ blowers, but there would be no way to know how accurate this might be. Theory tells us that the noise is a function of the total air volume (in cubic feet per minute) and the static pressure. It is well known that the fan blade design and some other aspects of the fan design impact the resultant noise generated, but that is' all we have to go on. Perhaps one day organ blower suppliers will provide sound data similar to that provided by some of the manufacturers of air handling equipment.**
2. **"Rigid Plenum Liner" manufactured by Knauf Fiberglass, Shelbyville IN. Telephone 800-825-4434.**
3. **"Noise Shield Regular Plenum Panel" manufactured by Industrial Acoustics Corporation, Bronx NY. Telephone 212-931-8000.**
4. **"Acousti K-27 Duct, spiral lockseam" manufactured by United McGill Corporation, Columbus OH. Telephone 614-433-5520.**
5. **"Rigid Round" manufactured by Manville, Denver CO. Telephone 303-978-4900.**

This article was first presented by Mr. Kahn as a lecture at the 1991 AIO convention in Minneapolis.

McManis voicing seminar now accepting registrations

The AIO mid-year seminar in Waterbury, Connecticut will be hosted by Charles McManis in early February. AIO members wishing to attend (and who did not already pre-register at the Portland convention) may photocopy the registration form on the facing page and mail it to the Houston office. The deadline for receiving this form along with a check for the full seminar fee is December 31.

The 15 members who pre-registered in Portland will participate in the first hands-on voicing session on Saturday afternoon. Members who register on the form provided here must wait until the second voicing session on Sunday afternoon to get their hands-on voicing experience (of course, this group may also watch and listen during the Saturday session). Those who are staying for the Sunday session may also wish to attend morning services at St. John's Episcopal Church (a III/56 McManis that will be examined during the seminar) or Sacred Heart Catholic Church, which has a restored 3-manual Johnson with Barker levers.

A full summary of the seminar was published in the September 1992 issue of this journal. The complete schedule and travel information will be mailed on January 1 to those who register by December 31. Members who would like further information about the topics to be covered during the seminar may call Charles McManis at (203) 266-4066.