



WALL CAVITY MICROPHONE TURBULENCE SHIELD

It is known in the art of acoustic sensing in duct active noise control (ANC) systems that the rejection of pressure fluctuations due to turbulence on the input or error microphone(s) of the system is critical to its ability to cancel noise. This so-called "flow noise" reduces the coherence between the sense and error microphones and the level of coherence is directly related to the achievable level of noise cancellation. For example, in a feedforward ANC system, a sense-error microphone coherence level of 0.99 is required to achieve a 20 dB cancellation level and a coherence value of 0.9 reduces the cancellation level to 10 dB. For the collocated feedback approach (so-called "TCM", for tight coupled monopole) the flow noise level on the input microphone limits the performance of the system because it represents the lowest sound level which can be achieved by active cancellation if the system worked perfectly. In addition, high-amplitude low-frequency flow fluctuations sensed by the microphone cause destructive high amplitude speaker motions and system instabilities. If sufficient rejection of turbulence is not possible with a given wind screen or shield, the only recourse is to move the ANC system away from the high turbulence region, typically near the fan, to a more quiescent region. This approach, in effect, increases the overall system length, and/or cross sectional size of the duct size of the ANC system and limits product integration since the microphone cannot be located in the vicinity of the fan discharge. A typical flow shielding approach used in standard ANC, HVAC applications is the use of a flush-mounted microphone which is located under the standard duct liner material. This configuration offers an inexpensive and effective means to reject the undesired flow noise. However, under extreme turbulence conditions, such as are encountered near the fan exit, this approach is insufficient. Thus, inherently this solution requires a greater system length due to the need to space the microphone from the fan exit.

The present invention places a microphone in a cavity outside of the duct liner thereby dramatically improving the performance such that the microphone can be located at the fan outlet while avoiding turbulence related problems. Additionally, the microphone can be located in a chamber which is located in a cavity which is divided

into a number of chambers by one or more porous partitions, at least one of which contains a microphone.

It is an object of this invention to permit the locating of sensor microphones adjacent to areas of extreme turbulence while maintaining high levels of coherence between the input and error microphones.

It is another object of this invention to provide a turbulence shield for a microphone.

It is a further object of this invention to provide a microphone turbulence shield suitable for locating in the region of the outlet of a fan. These objects, and others as will become apparent hereinafter, are accomplished by the present invention.

Basically, a sensor microphone is placed in a cavity outside of the duct liner of a duct of an ANC system. Baffles of porous material may be provided in the cavity to reduce internal flow recirculation.

Figure 1 is a schematic representation showing an ANC system for ducted systems employing an adaptive feedforward approach;

Figure 2 is a schematic representation showing an ANC system for ducted systems employing a collocated feedback approach;

Figure 3 is a sectional view of a first embodiment of the turbulence shield of the present invention;

Figure 4 is a sectional view taken along line 4-4 of Figure 3;

Figure 5 is a sectional view of the Figure 3 embodiment rotated 90° with respect to the duct;

Figure 6 is a sectional view of a second embodiment of the present invention;

Figure 7 is a sectional view of a third embodiment of the present invention;

Figure 8 is a sectional view of a fourth embodiment of the present invention;

Figure 9 is a sectional view of a fifth embodiment of the present invention;

Figure 10 is a graph showing the coherence between two microphones at the same cross plane with different flow shielding;

Figure 11 is a sectional view corresponding to Figure 5 but with two microphones;

Figure 12 is a sectional view corresponding to Figure 3, but with two microphones;

Figure 13 is a graph showing the coherence between faced and unfaced duct liner;

Figure 14 is a sectional view of a sixth embodiment of the present invention; and

Figure 15 is a sectional view taken along lines 15-15 of Figure 14.

In Figures 1 and 2, the numeral 10 generally designates a duct such as that used in the distribution of conditioned air and is lined with a standard duct liner material such as one inch thick fiber glass insulation. Preferably, the duct liner material is porous but resistant to flow therethrough due to the presence of a facing such as a covering or coating. One such suitable material is a plastic coated, mat faced fiber glass mat available from Manville Fiber Glass Group under the trade name Linacoustic. The upstream fan 12 produces noise, primarily due to aerodynamically-driven noise mechanisms, such as trailing-edge noise, which propagates down the duct. An effective means to control the lowest frequencies of this noise, developed in recent years, is active noise control, whereby a control speaker 14 is used to create an opposite-sign pressure disturbance in order to "cancel" the undesired noise. This cancellation is effected either by reflecting the sound back toward the source (i.e. a

purely reactive system), absorbing the sound energy by the control speaker 14, or by a combination of both such mechanisms. Figures 1 and 2 show the two principal means to achieve duct ANC (active noise control), adaptive feedforward in Figure 1 and collocated feedback in Figure 2. For the adaptive feedforward approach of Figure 1, a sense microphone 16 detects the propagating noise and feeds this signal forward through an adaptive DSP (digital signal processor) controller 18 which compensates the signal for time delay, attenuation of the sound amplitude, duct modes, speaker dynamics, etc. and supplies a signal to the control speaker 14 which cancels the noise. A downstream error microphone 20 detects the residual noise. The signal from the downstream microphone 20 is used to adapt the coefficients of the DSP 18 in such a manner as to minimize this residual noise signal at the error microphone 20. The collocated feedback approach of Figure 2 employs microphone 22 which measures the summed fan noise and speaker noise, an analog controller 24, and a control speaker 14. The signal from microphone 22 is input to the analog controller 24 which continuously adjusts the output of control speaker 14 to minimize the signal detected by microphone 22. In general, the adaptive feedforward approach of Figure 1 allows higher performance than the feedback approach of Figure 2, but at the expense of system length and cost.

For either duct ANC system, it is advantageous to locate the system as close as possible to the discharge of the fan, (i.e. minimize length D), the distance between the discharge of fan 12 and the nearest microphone 16 or 22, in order to minimize space requirements for the system. However, the turbulence T in the nearfield of the fan discharge is extreme and prevents fully employing this strategy. Such turbulence fluctuations may exceed 50% of the average flow speed in the duct 10. The pressure oscillations caused by the turbulent structures impinging on the microphones 16 and 22 generate a "flow noise" signal that adds with the acoustic pressure oscillations. The flow noise will limit the amount of noise cancellation which can be achieved by the ANC system. For example, if the flow noise is lower than the acoustic noise, the attenuation will be limited to that fraction of the acoustical signal which can be detected above the flow noise floor. Moreover, if the flow noise is higher than the acoustic noise, then the ANC system will broadcast the flow noise through the control

speaker, thereby being a noise generator rather than a noise attenuator. To increase the attenuation capability of the ANC system four options can be considered: (1) move the ANC system downstream to a more quiescent flow region, (2) electronically filter the flow noise from the signal from microphone 16 before it is input into the controller 18, or from microphone 22 before it is input into controller 24, (3) use an array of sense microphones with appropriate signal conditioning to electronically separate the flow-induced noise from the propagating noise in the duct 10, and (4) use a turbulence suppression shield around microphones 16, 20 and 22 to selectively reduce the strength of the turbulence energy at the microphone face relative to the strength of the propagating acoustical noise signal in the duct 10. Option (4), the use of a turbulence suppression shield around the sense microphone, is the desired option and a unique, high performance shielding concept is the subject of this invention.

The present invention permits the locating of microphone 16 in the region of turbulence T, associated with the discharge of fan 12 as well as providing additional shielding when used with microphones 20 and 22. Referring now to Figures 3 and 4 it is evident that cover member 30 defines three dimensional cavity 32 with an open side. The cavity is elongated in the direction of flow, indicated by arrows in Figure 3, and in one embodiment has the dimensions of twenty inches in length, ten inches in width and three inches in depth. Another embodiment is ten inches by five inches by three inches. Cover member 30 has a peripheral flange 30-1 to permit securing of cover 30 to duct 10. Porous material 34 which is normally of the same material as duct liner 11, and therefore faced or covered, divides cavity 32 into chamber 32-1 and 32-2. Accordingly, liner 11 and partition defining porous material 34 provide flow attenuation which is enhanced by the facing or covering. Microphone 16 is illustrated as located in upstream chamber 32-1 but it may also be located in chamber 32-2. Opening 10-1 is located in duct 10, at or near the outlet of fan 12, and is sized to correspond to the open side of cover 30 and is overlain by duct liner 11 such that only duct liner 11 separates the interior of duct 10 from cavity 32. Cover 30 is secured to the outside of duct 10 by screws 38, or any other suitable attachment means. If required, or desired, a gasket or seal may be located between the flanges of cover 30

and duct 10 since air leakage may result in flow noise and it is necessary that the cover is air tight and that it acts to contain the sound.

In operation, the fan generated noise readily passes through duct liner 11 into chambers 32-1 and 32-2 of cavity 32 where it is sensed by microphone 16. The duct liner 11 provides a restriction relative to turbulence T flowing into cavity 32. Additionally, porous material 34 which partitions cavity 32 into chambers 32-1 and 32-2 attenuates internal flow recirculation between chambers 32-1 and 32-2. The attenuation of internal flow recirculation is a result of the relationship of the significant size of opening 10-1 to average out the noise generated at the liner by turbulence which also facilitates the passage of turbulence flow through the duct liner 11 which overlies opening 10-1. Porous material 34, acting as a partition, effectively counteracts the effects of the significant size of opening 10-1 with respect to recirculating flow within the cavity 32.

Figure 5 is the same as the device of Figures 3 and 4 except that cover 30 is rotated 90°. The consequence of the repositioning is that cover 30 requires less length of duct 10 for placement, opening 10-1 extends a shorter distance in the direction of flow and both chambers 32-1 and 32-2 are in the same position relative to the length of duct 10. The operation of the device in the Figure 5 position would be the same as that of Figures 3 and 4.

In the Figure 6 embodiment, the partition defined by porous material 34, has been replaced with porous material partitions 134-1 and 134-2 so that cavity 32 is divided into chambers 132-1, 132-2 and 132-3 which are smaller than corresponding chambers 32-1 and 32-2. Microphone 16 can be satisfactorily located in any one of chambers 132-1, 132-2 and 132-3 but by locating it in chamber 132-2 three of the six sides of the chamber 132-2 are made up of porous material whereas only two of the six sides of the chambers 132-2 and 132-3 are made up of porous material. The extra side of porous material in chamber 132-2 provides an extra measure against recirculating flow effects, as described above, as does the smaller chamber, as

compared to chambers 32-1 and 32-2. Otherwise the operation of the Figure 6 device is the same as that of Figures 3 and 4.

In the Figure 7 embodiment, duct 10 is unlined so that opening 10-1 would provide free communication between the interior of duct 10 and cavity 32. Accordingly, porous material 111 is located in cover 30 and extends into cavity 32 so as to close the otherwise open side of cover 30 and provide a flush surface with the inside of duct wall 10. Cavity 32 is then divided into chambers 232-1 and 232-2 by porous material 234 which forms a partition. Rather than locating microphone 16 totally within chamber 232-1, it extends through one side, specifically the bottom, of cover 30, so as to be flush therewith, but this is possible in any of the other embodiments of the present invention as is further extending the microphone into the cavity. Further, it is only necessary that the microphone be responsive to acoustic pressure in the cavity 32 and it can be located outside of the cavity 32 but in fluid communication via a tube or the like. Because the porous material 111 is located within cover 30, assuming the same dimensions of cover 30, chambers 232-1 and 232-2 will be smaller than chambers 32-1 and 32-2 but otherwise the operations of the Figure 7 device would be the same as that of Figures 3 and 4. If desired, porous material 111 alone or in combination with porous material 234 may fill most, or all, of cavity 32. This option is enhanced by the flush placement of microphone 16.

In the Figure 8 embodiment, porous material 334 is located within cavity 32 parallel to and spaced from duct liner 11 so as to form a partition in cavity 32 dividing it into chambers 332-1 and 332-2. Chamber 332-1 and porous material partition 334 are located between cavity chamber 332-2 and the interior of duct 10 thereby providing an extra measure of reducing internal flow recirculation relative to chamber 332-2. Accordingly, microphone 16 is preferably located in chamber 332-2. The operation of the embodiment of Figure 8 is basically the same as that of the Figure 3 and 4 embodiment.

In the Figure 9 embodiment, cover 430 is of a three dimensional parabolic shape in the illustrated section. Because of the parabolic shape, the small wavelength (i.e.

wall-generated turbulence) noise reaching cavity 432 is reflected by the interior surface of cover 430 to the focus of the parabola. This focusing of the small wavelength turbulent pressure fluctuations allows greater averaging thereby minimizing its effects. Larger wave length sound energy (i.e. fan noise) remains essentially unaffected by the presence of the reflective surface. Microphone 16 is located at the focus of the parabola and, preferably within partition defining insulation material 434 which divides cavity 432 into chambers 432-1 and 432-2. Although a parabolic shape is specifically illustrated, there are other shapes such as a portion of a three dimensional ellipse that has a focus to which noise would be reflected. Except for the focusing of the turbulence noise and the locating of the microphone 16 at the focus, the Figure 9 embodiment will essentially operate the same as the Figure 3 and 4 device relative to reducing internal flow recirculation.

Figure 10 shows the performance of the flush mounted and present invention wall cavity turbulence shield concept of the present invention in terms of the coherence between two identically shielded microphones at the same cross plane obtained in a twenty five ton vertical packaged air conditioner, VPAC, unit just downstream of the fan discharge and 90° turn (turbulence levels equal to 25-30% based on bulk averaged velocity). The addition of the liner dramatically increases the coherence above 20Hz, with little effect below 20Hz. The addition of the cover (20 inches x 10 inches x 3 inches) is seen to significantly improve the coherence over the entire band and with three vertically oriented internal baffles or partitions of porous material to attenuate internal flow recirculation, the coherence is even further improved, particularly at low frequency.

One or more additional microphones can be added to the cavity 32 and summed to improve the coherent sound energy measured from the fan 12. For example, coherent sound energy will increase at a rate of 6 dB for each doubling of the number of microphones/sensors whereas incoherent sound, i.e. turbulent noise, will add as 3 dB for each doubling of the number of microphones/sensors. The microphones/sensors would be spaced at a distance greater than the coherent length of the turbulence. Referring now to Figure 11, it corresponds to Figure 5 except that microphone 16-1

has been added and is located in cavity 32-2. Because microphones 16 and 16-1 are the same distance from the fan 12, they are directly connected to adder 50. Referring now to Figure 12, it corresponds to Figure 11 except that cover 30 is rotated 90° clockwise. This results in microphone 16-1 and chamber 32-2 being downstream of microphone 16 and chamber 32-1 relative to fan 12. Accordingly, there is a time delay, $\Delta\tau$, between microphones 16 and 16-1 and microphone 16 is connected to adder 50 via time delay 60 whereas microphone 16-1 is connected directly to adder 50.

As noted above, the duct liner 11 and partitions 34, 134-1, 134-2, 234, 334 and 434 are preferably of the same material, fiber glass, which is porous, with a facing or covering which makes it more resistant to flow therethrough. Figure 13 shows the increase in coherence due to the presence of a facing on the fiber glass.

Referring now to Figures 14 and 15, the housing or protrusion 110-1 defining the cavity 532 may be integral with the duct or fan outlet 110. A major advantage of this embodiment is the degree of air tightness since the only opening required in housing 110-1 is for the electrical connection to microphones 16 and 16-1 which are in chambers 532-1 and 532-2, respectively. Additionally, the housing 110-1 is of the same material as duct or fan outlet 110 and will have the same ability to contain the sound/noise. The embodiment of Figures 14 and 15 directly corresponds to the embodiment of Figure 12 and, if rotated 90°, the Figure 11 embodiment, but the embodiments of Figures 3-9 could also have their covers integral with the duct without changing their basic function. Accordingly, the illustration of modified embodiments of the Figures 3-9 devices to show covers integral with the duct or fan outlet is unnecessary as providing no additional information or teaching.

Although preferred embodiments of the present invention have been described and illustrated, other changes will occur to those skilled in the art. For example, more chambers may be formed, the chambers may be of unequal size and/or of different orientations. Also, the microphones need only be responsive to acoustic pressure in said cavity so that it is not necessary to physically locate the microphone(s) in the cavity. This will be helpful where the dimensions of the cavity are small relative to a

microphone and baffling. It is therefore intended that the scope of the present invention is to be limited only by the scope of the appended claims.

CLAIMS

What is Claimed is:

1. In a duct active noise cancellation system including a noise producing fan (12) and a fan discharge having flow turbulence therein, air distributing means including said fan discharge and defined at least in part by a duct (10), having a wall and an interior, a turbulence shield characterized by:

means defining a cavity (32; 432; 532) having an open end;

said means defining a cavity being located adjacent to said duct so that said open end corresponds to an opening in said wall;

flow attenuation means (11; 111) located between said interior and said cavity;

at least one sound sensing means (16; 16-1) located so as to be responsive to acoustic pressure in said cavity such that said sound sensing means is separated from said interior by said flow attenuation means.

2. The turbulence shield of claim 1 wherein said flow attenuation means is the only physical barrier between said interior and said at least one sound sensing means.

3. The turbulence shield of claim 1 wherein said flow attenuation means at least partially fills said cavity.

4. The turbulence shield of claim 1 wherein said cavity is partitioned into a plurality of chambers.

5. The turbulence shield of claim 4 wherein said at least one sound sensing means is at least partially located in a first one (332-2) of said plurality of chambers and a second one (332-1) of said plurality of chambers is located between said first one of said plurality of chambers and said interior.

6. The turbulence shield of claim 4 wherein said at least one sound sensing means (16) is located in one of said plurality of chambers.



7. The turbulence shield of claim 6 further including a second sound sensing means (16-2) which is at least partially located in a second one of said plurality of chambers.

8. The turbulence shield of claim 7 wherein said first one of said plurality of chambers is located upstream of said second one of said plurality of chambers.

9. The turbulence shield of claim 4 wherein said cavity has a three dimensional parabolic shape.

10. The turbulence shield of claim 4 wherein flow attenuation means is used to partition said cavity into a plurality of chambers.

11. The turbulence shield of claim 10 wherein said at least one sound sensing means is located in said flow attenuation means which partitions said cavity into a plurality of chambers.

12. The turbulence shield of claim 1 wherein said cover has a parabolic shape.

13. The turbulence shield of claim 12 wherein said at least one sound sensing means is located in flow attenuation means which partitions said cavity into a plurality of chambers.

14. The turbulence shield of claim 1 wherein said cover and said cavity formed thereby is shaped so as to reflect sound to a focus.

15. The turbulence shield of claim 14 wherein said at least one sound sensing means is located at said focus.



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