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FLOW NOISE INTERACTIONS FOR DUCTED SILENCERS IN ELBOW TURNING HVAC SYSTEMS

E. Mouratidis

Vibro-Acoustics, 727 Tapscott Rd., M1X 1A2, Toronto, Ontario, Canada

Tel.: 416-291-7371 / Fax: 416-291-8049 / Email: emouratidis@vibro-acoustics.com

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ABSTRACT

In HVAC systems, space and size restraints place limitations on optimal duct silencer installations. A silencer is often located in less than ideal locations, relative to a fan or other duct components. This study investigates the straight silencer flow noise interaction created by the close proximity to a sheet metal contractor's elbow turn. Airflow interactions, produced by turbulence effects in the duct between the elbow turn and the silencer, create aero-acoustic system effects. These effects adversely alter the self-generated flow noise of duct silencers. There is no known study which has clearly identified this type of flow noise interaction. Gordon (1968) and Hirschorn (1981) investigated this system phenomena, but little information was available in terms of flow noise effects and how they related to reported aerodynamic pressure loss system effects. Neise (1992) investigated similar duct and fan noise mechanisms, but this can only serve as a general guide to silencer applications in ducted systems. Using a laboratory's straight and elbow wind tunnel facility, complete aero-acoustic silencer performance was determined in accordance with certified test methods. This produced flow noise levels for straight silencers in ideal conditions and under three typical installation conditions: 1) upstream vs. downstream position relative to the duct turn; 2) silencer air passage orientation relative to the plane of turn; and 3) using three different elbow geometry types [radius, square, and square with turning vanes]. This study represents an identification of a very specialized flow noise interaction, which may lead towards a better understanding of this adverse airflow phenomena in ducted systems.

1 - INTRODUCTION

In typical HVAC systems, space restraints and cost concerns may require the installation of a passive duct silencer within 3 duct diameters of a contractor's elbow section or other duct component. *Harris et al* describes 'ideal' silencer locations as, "... located in a system so that they receive reasonably non-turbulent air flow, usually at a minimum distance of 3 duct diameters (along a straight run of duct) from the nearest fan, elbow or turn." It is believed that a less than ideal installation creates an adverse interaction between the performance of the duct silencer and the performance of the elbow (90 degree turn). This acoustic and aerodynamic interaction is termed system effects.

The performance of a duct silencer is determined through the procedures outlined in the ASTM E477 test standard, entitled "Standard Test Method for Measuring Acoustical and Airflow Performance of Duct Liner Materials and Prefabricated Silencers." The standard defines a silencer test as one which includes at least 5 equivalent duct diameters upstream and 10 equivalent duct diameters downstream of straight, uniform cross-sectional area duct. This will ensure the accuracy of the aerodynamic pressure loss measurement (Total Pressure Drop) and the resulting flow noise levels will be uninfluenced. All silencer manufacturer's performance ratings are based on these ideal conditions.

Real-life systems rarely resemble the test condition. In fact, it is quite common for silencers to be installed between 0 to 3 duct diameters from a typical HVAC elbow. The magnitude of the resulting interaction is believed to be similar to that of ducted fans. Further, "the aerodynamic system effect depends upon the internal geometry of the silencer, the geometry of the duct system, and how the silencer fits into the duct system" (Guenther, 1998). It is unknown what scalar quantity each of the above parameters apply to the overall system flow noise due to their interdependence. Therefore, in the absence of reliable test models and derived relationships, users of silencer performance data tend to generalize these aero-acoustic effects, and in some cases incorrectly ignore them all together. This paper will attempt to identify the self generated flow noise interaction of straight passive duct silencers within elbow duct systems.

2 - PHYSICAL PHENOMENA

A silencer's aerodynamic flow noise is defined as the sound power induced by flow turbulence into and out of its internal baffles. It is a broadband type of noise which is determined by flow intensity and internal silencer geometry. In ducted ventilation systems, the airflow remains turbulent and unsteady for a considerable distance from the fan. The various duct discontinuities present (e.g. turns, area changes, branches, silencers, etc.) react to produce even higher levels of turbulence.

For a duct silencer, the air moving through the internal air passage(s) produces a turbulent wake immediately downstream. This phenomena is similar to a jet of airflow, and is followed by a region of highly turbulent energy known as the mixing region. Duct components installed within 3 duct diameters downstream from the silencer are considered to be in the turbulent mixing region. This produces unique pressure drop and flow noise characteristics. It is unknown if these two performance characteristics are directly related in ducted systems. Similarly, this phenomena will occur on the upstream side of the duct silencer. In this case, the energy discharging from the duct element produces a turbulent interaction with the silencer inlet.

3 - TEST ENVIRONMENT

Using the facilities of the Vibro-Acoustics' Aero-Acoustic Laboratory, the performance of duct silencers can be studied in either an elbow or straight through orientation. The facility is accredited for silencer testing under the ASTM E477 test standard and for sound power determination under the ANSI S12.31 test standard. The method used for calculating sound power is the Comparison Method, which incorporates the use of a calibrated reference sound source. The facility's 570 m^3 reverberation chamber produces reliable and repeatable sound pressure measurements between 50 to 10,000Hz. The availability of this lower frequency range is ideal for the acoustical measurements in this study.

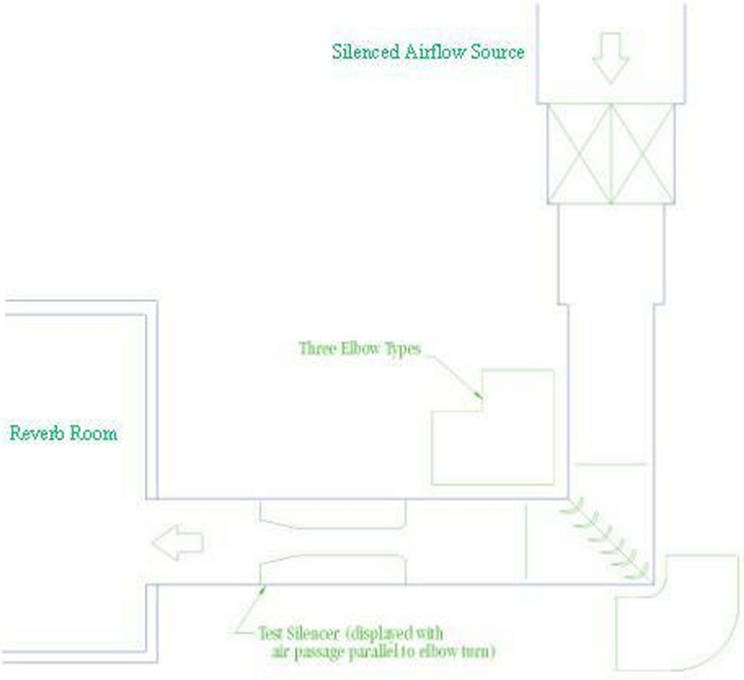

Figure 1: Typical test rig for a straight silencer installation in an elbow system.

Initially, seven straight silencers were studied in a straight through duct for complete acoustical and aerodynamic performance. This represents ideal silencer flow noise performance. Each specimen was then installed in an elbow wind tunnel system configuration (figure 1), using three 90 degree turning elbows ([i] square with no turning vanes, [ii] square with turning vanes, and [iii] radius with no turning vanes). These three elbows are representative of 'typical' designs found in today's HVAC systems. Quiet airflow (3.8-to-7.6 m/s) was delivered through the test duct to produce the corresponding self-generated noise levels.

The test specimen were absorptive types (filled with acoustic media) and designed with 760 ×600 ×1500mm external casings. Internally they differed in terms of aerodynamic baffle geometry and configuration. This varied the inlet and discharge conditions of each silencer, so that a diverse range in aero-acoustic conditions would be simulated. The test specimen construction materials were all standard HVAC specifications. Each silencer was installed in the three different elbow configurations at specific locations upstream and downstream relative to the turn. For the radius elbow set-up, the silencers were installed at D=0 and D=1 equivalent duct diameter away from the elbows. For the two square elbows, the silencers were installed at D=0, D=1, and D=2 equivalent duct diameters away from the elbows.

4 - GENERATED NOISE PERFORMANCE

The generated flow noise of both the silencer in ideal conditions and in the elbow system duct was calculated using reverberation room sound pressure measurements. Observations are provided in terms of: 1) upstream versus downstream installations [figures 2 & 3]; 2) air passage orientation relative to the turn [figure 4]; and 3) elbow turn geometry [figure 5].

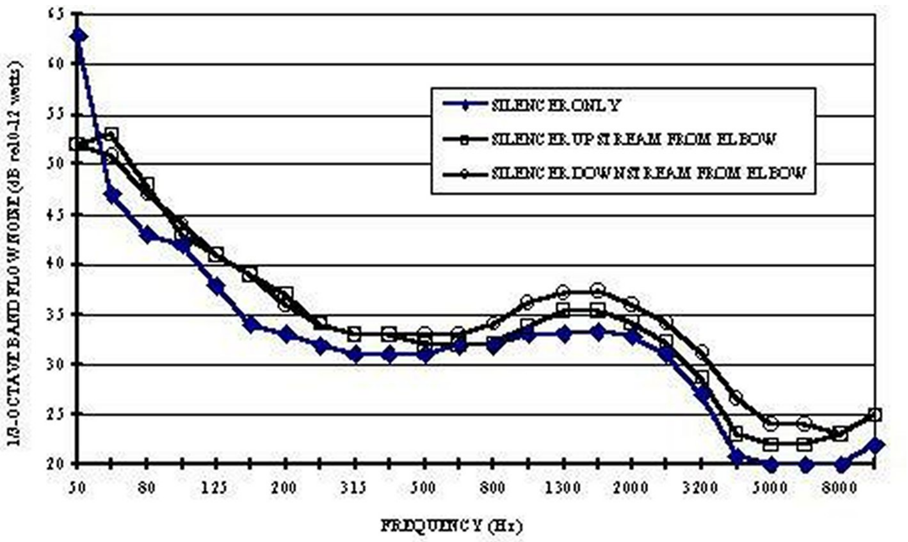

Figure 2: Upstream vs. downstream silencer installations relative to a radius elbow turn.

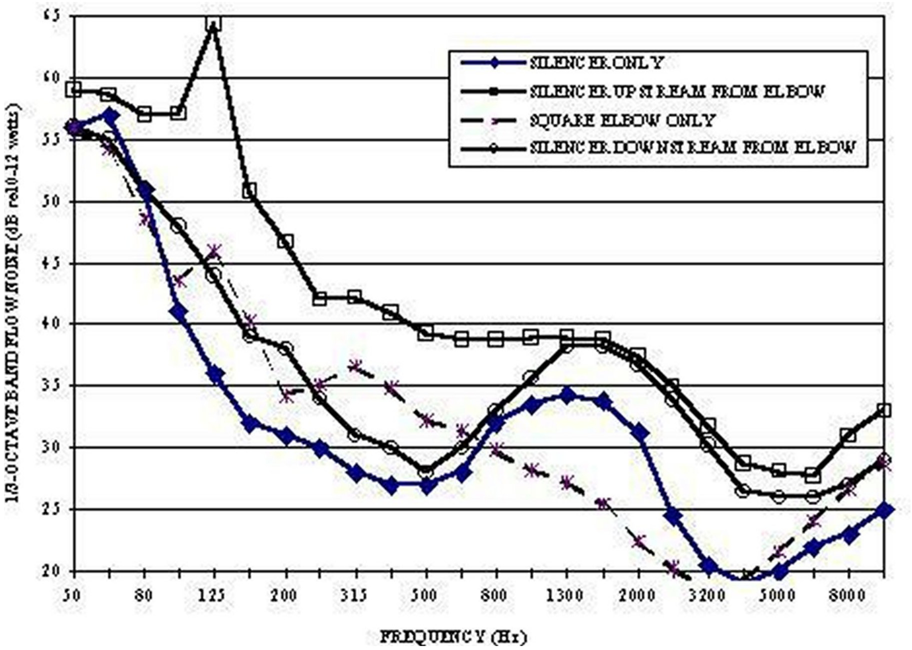

Figure 3: Upstream versus downstream installations relative to a square elbow turn.

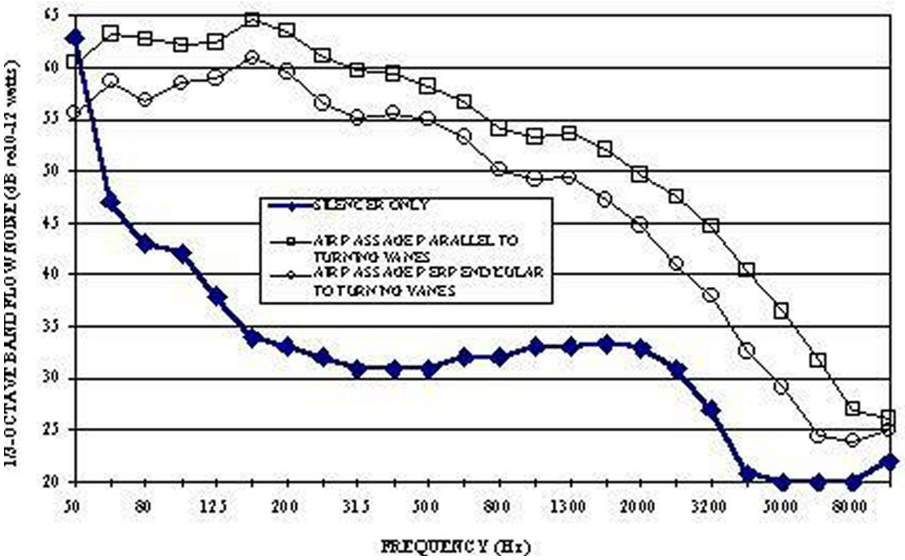

Figure 4: Air passage orientation variable, with silencer installed at D=0 upstream from a square elbow with turning vanes.

In the radius elbow system, there was an insignificant flow noise difference for upstream and downstream installations. For both the square elbow and square elbow with turning vanes systems, the upstream installation produced the highest low-to-mid frequency levels, as compared to the similar downstream position. The downstream silencer installations quite often produced flow noise spectrums similar to the empty elbow turn, which indicates that the silencer interaction in this case is negligible. Overall, as the silencer distance relative to the elbow turn increased, the broadband flow noise approached the noise floor (defined by either the silencer or the elbow turn on its own).

Variables in the silencer air passage orientation, relative to the duct plane, produced negligible differences for all variables investigated, except for the silencer upstream installation results of the elbow with turning vanes. In this particular case, air passages parallel to the elbow turn forced unbalanced, high volumes of airflow through the turning vane assembly. This resulted in approximately 6dB rise in flow noise, at both the D=0 and D=1 installations.

Generally, all three elbow types studied increased the overall system flow noise due to silencer-elbow interactions. For the majority of silencer downstream installations, all three elbow types produced approximately equal absolute flow noise levels. Conversely, for the silencer upstream installations, the turning vane system produced the highest levels (5-20dB rise), while the radius system resulted in the smallest system interactions (3-5dB rise).

5 - CONCLUSIONS

The test specimen used in this study were all absorptive, with either one or two air passages. The duct cross-section used was 0.46 square meters. Therefore, the reported results are applicable to similar real-life systems. Larger duct widths, such as 1500 to 2000mm, may produce different low frequency performance characteristics. Also, silencers with more than 2 air passages or designs which do not use absorptive media fills, may produce different aero-acoustic effects than the observed results in this study.

This paper examined the aero-acoustic interaction of straight silencers with three HVAC elbow sections. This interaction, which is known as a system effect, results in adversely affected self-generated flow noise. Considerable increases were found for square elbow turns, with the turning vane assembly creating the highest absolute levels. This rise in flow noise may be significant in noise sensitive HVAC applications and should be further evaluated. Future investigations are required to quantify the real-life relationships, if any, between upstream and downstream locations, air passage orientation, and elbow turn types, to provide a better understanding of this type of system effect.

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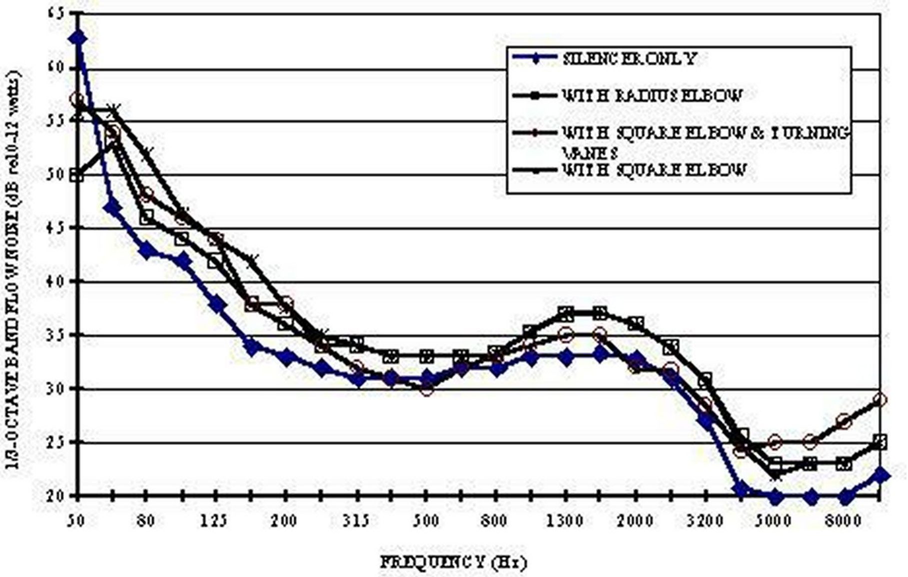

Figure 5: Three elbow types with silencer installed at D=1 duct diameter downstream.

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