END REFLECTION LOSS IN REAL DUCT SYSTEMS

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1 Introduction

Lighter building construction has contributed to a focus on low frequency (LF) noise. The LF is difficult to predict within a noise path analysis and potentially more arduous to mitigate once a mechanical system is installed. For fans and air distribution systems, there is a palpable need for a better understanding of LF as a means to improve equipment performance, sound quality and occupant comfort. One of the key considerations in LF noise control is the amount of attenuation realized by the duct termination. The current prediction tools indicate that a significant amount of LF sound will reflect back through the duct when a sudden area change is encountered. Limited research is available on system interactions for this vital acoustic phenomena found in most ventilation systems. This study may help improve the assessment of LF duct reflection in real systems.

2 Background

The LF physical phenomena called End Reflection Loss (ERL; dB) may be described as the apparent change in sound power observed at a duct termination, as derived by the difference between the incident and reflected sound power at the duct termination or boundary. ERL occurs in the plane wave region, defined at frequencies below the cut-off (f_c; Hz) for ducts or openings:

$$f_c = \frac{c}{2De} \qquad (1)$$

where: c = speed of sound in air (m/s); and,
De = equivalent duct diameter (m).

One of the earliest descriptions of ERL was found in the book Noise Reduction [1]. This was followed by handbooks published by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), called the Guide and Data Book [2]. This appears to be the basis of the ERL used today, including the current ASHRAE Handbook for both a flush termination and one that extends into a space. Recent research [3] has enhanced the understanding of ERL. This work included various termination conditions (diffusers, grilles and flexible ducts). This work did not focus on the impacts, if any, from the conditions further upstream from the termination. ERL is based on analytical assumptions for long, straight duct sections. ASHRAE provides a cautionary note: "Many air distribution systems and fan equipment do not have long straight sections (greater than 3xDe)…effects of these configurations on ERL are not known". The literature does not provide any further guidance on the system related impacts. Real systems rarely provide more than 3 x De of uniform duct immediately ahead of the termination. For example, a fan intake may be open to atmosphere, and HVAC systems normally include elbow turns and off-sets between the fan and the termination. Uniform plane wave action may be rare in real systems, thus ERL may be subject to End Reflection System Effects (ERSE).

3 Experimental Study

This study was not configured to measure ERL directly. The effects could be observed indirectly through a controlled system configuration. The testing was conducted in the *VAW Systems Noise Control Applications Laboratory* (NCAL), located in Newmarket, ON. The apparatus is based on the applicable sections of the ISO 7235 [4] and the ASTM E477 [5] standards. The set-up (Figure 1) includes a large, absorptive source chamber housing loudspeakers that produce broadband pink noise. The source is connected to a modular wind tunnel consisting of heavy steel walls. The NCAL offers the ability to readily modify the wind tunnel into straight, elbow and multi-elbow configurations. Two duct configurations (Table 1) were assessed: (1) straight; and, (2) double-elbow. The uniform duct between the miter elbow and the termination was 8xDe. The measurements were made with a sound intensity system, including both in-duct and end-of-duct sound intensity levels (Li; dB). The sound power levels (Lw; dB ref10^{-12} watts) in this study are derived from the Li data as per the ISO 9614-3 [6] standard.

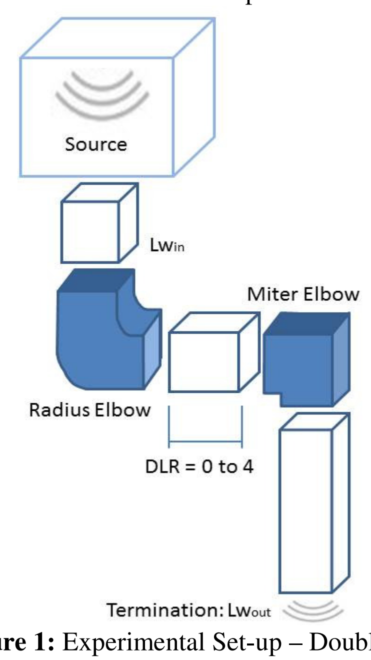

Figure 1: Experimental Set-up – Double-Elbow

Configuration	Size (mm)	Cut-off Freq. (Hz)
Straight	900x600	207
Double Elbow	600x600	253

Table 1: Wind Tunnel Set-up

The straight duct layout is rarely encountered in real systems, thus may be considered a baseline condition. The length of the wind tunnel was set to a Duct Length Ratio (DLR) of 0, 6, 10 and 16, where DLR may be defined as:

$$DLR = \frac{WindTunnel\ Length}{De} \quad (2)$$

The double elbow layout allows for an evaluation of a common interaction between a radius and miter fitting. The space between the elbows was set to a DLR of 0, 1, 2 and 4.

4 Results

The measured Lw at the termination (Lw_{out}) is corrected (Lw_{out*}) at each 1/3-octave band frequency with the attenuation of the additional duct (IL_{DLR}), as follows:

$$Lw_{out*} = Lw_{out} + IL_{DLR} \quad (3)$$

The straight wind tunnel resulted in a near constant sound power into the system (Lw_{in}) for changing DLR. As highlighted in Table 2, the standard deviation (SD, dB) of the Lw_{in} was significantly smaller than the corresponding SD of the Lw_{out*} for the measurements taken at four DLR. Similar results were found for the double elbow configuration. Over the range of DLR in this study, the Lw_{in} was relatively constant, while the corresponding Lw_{out*} varied significantly for relatively small system changes.

Measurement Location	Third-Octave Band Frequency (Hz)					
	50	63	80	100	125	160
Lw_{in}	0.69	0.33	0.10	0.33	0.17	0.18
Lw_{out*}	1.07	2.57	1.39	0.97	0.93	0.42

Table 2: SD (dB) of Lw_{in} and Lw_{out*} for Straight Duct

The Lw_{out*} may be investigated closely while under apparent constant Lw_{in}. As shown in Figure 2, the LF Lw_{out*} varied at a level close to the corresponding ERL.

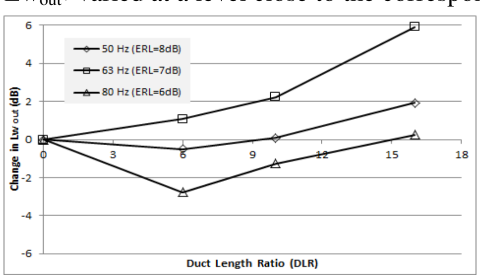

Figure 2: Straight Duct Lw_{out*} for increasing DLR (50,63&80Hz)

As shown in Figure 3, the double-elbow configuration resulted in a similar Lw_{out*} trend for a small change in DLR.

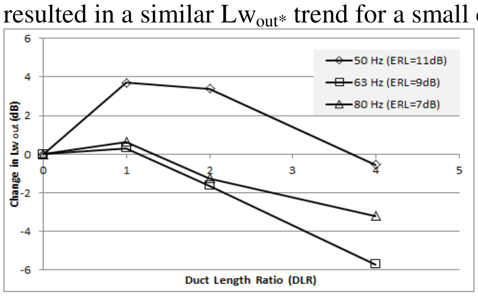

Figure 3: Double Elbow Lw_{out*} for increasing DLR (50,63&80Hz)

There is an apparent spread in the corrected sound power at the duct termination when the conditions upstream are varied. We may define the ERSE (Table 3) as the range in Lw_{out*}, as observed for various DLR, as follows:

$$ERSE = Lw_{out*}\ Max - Lw_{out*}\ Min \quad (4)$$

The Li measurements were taken at various locations, consisting of a microphone traverse that divided the section into 9 equal areas. This process created Li contours and were evaluated as: “Very Uniform” (all 9 measurements within +/- 1 dB); “Uniform” (all 9 measurements within +/- 2 dB); and, “Not Uniform” (>3 dB spread). Changing the space between the two elbows form DLR = 0 to 2 did not impact the Li contours near the source and at the termination. The corresponding Li contour at the miter elbow changed from Very Uniform to Not Uniform at 50 and 63 Hz. Virtually all of the contours at > 63 Hz were found to be Very Uniform for all measurement locations.

Duct System Configuration	Third-Octave Band Frequency (Hz)					
	50	63	80	100	125	160
Straight	2.4	5.9	3.0	2.3	1.8	0.9
Double Elbow	4.3	6.0	3.8	2.6	0.9	2.0

Table 3: Range in Lw_{out*} (ERSE; dB) for Apparent Constant Lw_{in}

5 Conclusion

The impacts on ERL may be observed through system duct changes. The configurations noted in this study are relatively straightforward, but resemble some real-life systems. In a controlled laboratory set-up, conditions ahead of the termination appear to significantly impact the apparent ERL, resulting in ERSE. In-duct measurements may provide some value in terms of identifying conditions where the ERSE may emerge. Users of the analytical ERL tools should apply the values with caution, as the ERSE appears to be close to the magnitude of the ERL itself. Further research may look at a potential relationship between the sound field in the duct and the resulting ERSE.

References

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[6] ISO 9614-3:2002 Acoustics - Determination of sound power levels of noise sources using sound intensity - Part 3: Precision method for measurement by scanning.