Canadian Acoustics / Acoustique Canadienne 18(3) 3-12 (1990)

PREDICTED ACOUSTICAL PERFORMANCE OF MULTI-UNIT SPLITTER SILENCERS

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Abstract

Passive silencers with acoustic fill are commonly used to reduce the fan noise in rectangular ducts of conventional air-handling systems. Design procedures for silencer performance evaluation of simple configurations have been available for some time. Design curves for a wide variety of rectangular silencers were made available recently. Many methods for predicting silencer insertion loss assume the silencers to be a single unit. In many air-handling systems however, the duct is divided into many small units by installing splitters in the duct. Predicted insertion loss results for multi-unit splitter silencers are presented in this paper. Multi-unit silencer performance is compared to that of a single unit within the full duct. The accuracy of using a single-unit model to represent the different types of conventional rectangular silencers is also presented.

Sommaire

Les conduits d'air rectangulaires dans les systèmes conventionnels sont composés de silencieux passifs accompagnés de remblai acoustique afin de réduire le bruit de ventilateur. Des procédures établies servant à evaluer le fonctionnement des silencieux à compartiment simple existent depuis quelque temps. Des courbes typiques représentant la ligne complète de silencieux rectangulaires ont récemment été disponibles. La perte dut a l'insertion calculée de façons diverses prenait pour acquis que les silencieux étaient composés d'une piece unique. Plusieurs conduits d'air sont réduits de taille par l'introduction de partitions.

Les résultats présentés dans cette dissertation, démontrent la perte dut à l'insertion de partitions dans les silencieux. La performance des silencieux à plusieurs compartiments est comparée à celle des silencieux à compartiment unique. L'exactitude de l'utilisation d'un modèle réservé aux silencieux à compartiment unique afin de représenter la ligne de silencieux conventionnels est également discutée.

1.0 Introduction

Fan noise in air-handling systems is conventionally reduced by the use of absorptive silencers. Theoretical models for describing the wave propagation in simple lined ducts as well as for predicting the acoustical insertion loss were presented by Scott [1], Morse [2] and Cremer [3]. Many prediction schemes are available [4, 5, 6, 7, 8, 9] and all are based on the two models of Scott [1] and Morse [2]. The differences in the various procedures are due to the amount of complexity applied while solving the mathematical model and range from the simplistic procedures [4] to the calculation of a large set of design curves [9].

All of the available prediction schemes assume that the passive silencers consist of a single unit, that is, acoustic fill - open air way - acoustic fill. In large air handling systems however, splitters are inserted to divide the duct into a number of identical single units. The prediction schemes assume that the insertion loss of splitter silencers can be predicted by calculating the performance of one single unit. Cummings [8] discussed the possible extension of a single-unit model to multi-unit splitter silencers. The use of a single-unit model to represent the rectangular splitter silencers must be validated.

The main aim of the present paper is to extend the results of Ramakrishnan and Ball [9] to include splitter silencers. The results of the present paper are limited to the range of rectangular silencers manufactured in conventional HVAC (Heating, Ventilating, Air Condtioning) systems [10, 11]. Silencer insertion loss results for two combinations of splitter silencers are presented in this paper. Results for a single-unit silencer are compared to those predcited by the multi-unit splitter models. The accuracy of using the results from a single-unit system to predict the performance of a wide variety of silencers is also presented.

2.0 System Description

2.1 System Criteria

The aim of the present paper is to present methods that are accurate within 3 dB in each frequency band of interest. A number of simplifications are therefore inherent in the procedure used to predict the insertion loss. The results presented in this paper are based on the theoretical model described in Ramakrishnan and Watson [12]; details are not presented here. The accuracy of the prediction procedure was validated for single-unit silencers in reference 12 by providing comparisons with experimental results. Results are applicable only to low-speed HVAC system ducts. Thus they are not applicable to, for example, aircraft engines or automobile mufflers.

2.2 Multi-unit Silencer Model

Three splitter silencer configurations commonly used in HVAC systems are shown in Figure 1. Single unit, two unit and three unit silencers have the same basic unit width 'M'. The dimensions of the basic unit are described using the general convention of major silencer manufacturers in Canada [10, 11]. It consists of a hard-walled duct with two liners of depth 'd' separated by an open air way of depth '2h'.

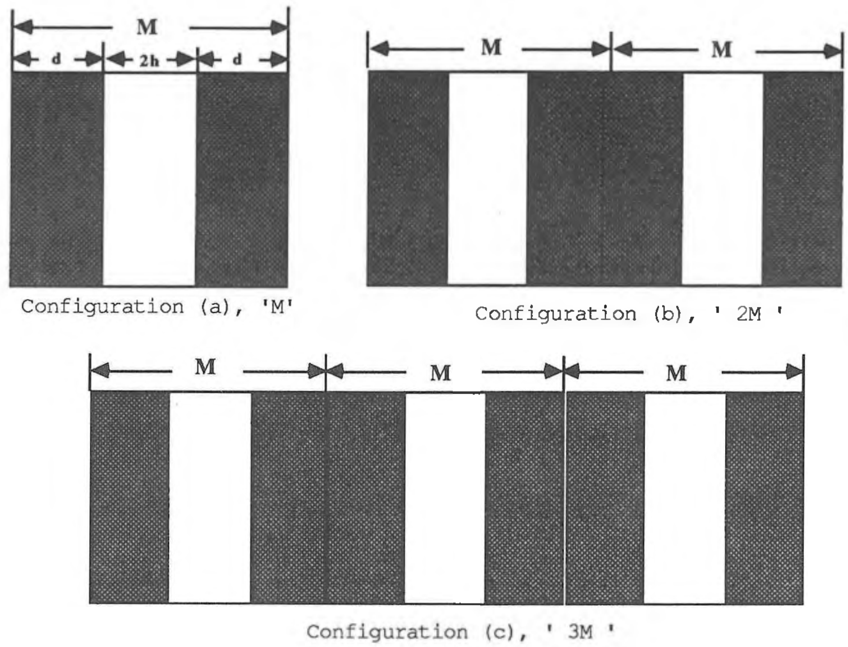

Figure 1. Types of Splitter Silencers.

Layers of isotropic, homogeneous sound absorbing material are used for the lining. The open airway of the duct is separated from the liners by sheets of perforated material with uniformly spaced holes.

Existing insertion loss prediction methods assume that a hard septum separates the basic units in a multi-unit system. This allows one to solve for the insertion loss of a single duct of size 'M'. The same result is then applied for silencers of size '2*M', '3*M' and so on. It is obvious that the above procedure is valid only if it can be shown that plane waves alone propagate in the duct system. The aim of the present work is to investigate the possibility of extending the same procedure for all possible propagating modes. A brief description of the solution procedure is given in the next section.

2.3 Prediction of Insertion Loss

The acoustical evaluation procedure follows conventional theoretical methods. The sound absorbing material is considered to be homogeneous, isotropic and made up of either foam or fibrous type materials. Even though the isotropic condition is not realistic, the differences in the insertion loss results between isotropic and anisotropic conditions are well within the required accuracy for HVAC system silencers [13]. The sound absorbing material is also treated as bulk reacting, unlike the local reaction model used in references 2 and 3. Propagation in the acoustic material is thus included with proper accounting of its bulk properties.

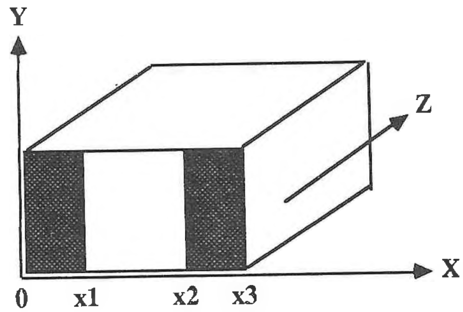

Figure 2. Co-ordinate System Used for the Analysis

The rectangular duct geometry and the coordinate system used are shown in Figure 2. The sound field in the duct is evaluated by solving the following set of wave equations:

$$\partial^2 p / \partial z^2 + \partial^2 p / \partial x^2 - (1 / c_1^2) \partial^2 p / \partial t^2 = 0 \quad (1)$$

$$\partial^2 p / \partial z^2 + \partial^2 p / \partial x^2 - (1 / c_2^2) \partial^2 p / \partial t^2 = 0 \quad (2)$$

Equation (1) is valid in the open air way [$x_1 \leq x \leq x_2$] with c_1 being the sound speed in air. Equation (2) is valid in the sound absorbing material [$0 \leq x \leq x_1$; $x_2 \leq x \leq x_3$] which has a complex sound speed of c_2. Pressure and velocity continuity are applied at the various interfaces between the absorbing material and open air way. The number of such interfaces is equal to twice the number of units in the duct system. For example, there are '2' interfaces for Configuration (a) and there are '6' interfaces for Configuration (c).

The two wave equations are solved for the common axial wave number k_z by applying a cubic finite element algorithm [12]. The propagation constant and characteristic impedance of the sound absorbing material are complex and are obtained from Beranek [5]. The real part of the axial wave number k_z is directly proportional to the attenuation rate per unit length of the silencer. All possible modes propagating in the 'X' direction are considered. Only those modes with slow rates of attenuation are summed to determine the final insertion loss on the assumption that these modes carry equal amounts of the incident sound energy.

3.0 Results and Discussion

The silencer unit size 'M' of conventional rectangular silencers varies from 250 mm (10 in.) to 910 mm (36 in.). The frequency range of interest is from 100 Hz to 10 kHz. The type of absorbing material is another variable that must be included. In addition, the ratio of 'd' to 'h', commonly represented by the open-area percentage, is varied between 0.5 and 3.0. Since it was not practical to present predictions for all combinations of the parameters, insertion loss results are generated for extreme values. The length of the silencer is chosen to be one metre.

The values chosen for the various parameters used in the calculations are as follows:

- Material type (Flow resistance in MKS Rayls / m): 8000, 20000
- 'M', the Unit Size (mm): 300, 600
- Open-Area Percentage (%): 25, 50
- Configuration of Splitters : 'M', '2M', '3M'

The insertion loss values reported by silencer manufacturers [10, 11] are usually limited to 50 dB. One main reason for such a convention is perhaps due to the fact that it is very difficult to measure insertion loss values more than 50 dB by any of the standardised test procedures [14]. The predicted results presented in this paper are not limited to 50 dB.

Unit Size 'M'	d / h	Material Rayls / m	Silencer Type	Frequency, Hz											
				125		250		500		1000		2000		4000	
				a	b	a	b	a	b	a	b	a	b	a	b
600 mm	1	8000	M	2	1	2	1	3	1	4	1	8	1	14	3
			3M	2	2	3	3	6	3	9	3	21	3	42	6
600 mm	1	20000	M	2	1	2	1	3	1	5	1	8	1	14	3
			3M	2	2	3	3	6	3	9	3	21	3	42	6
300 mm	1	8000	M	1	1	1	1	2	1	3	1	4	1	7	1
			3M	1	1	2	2	3	3	6	3	11	3	21	3
600 mm	3	8000	M	2	1	2	1	3	1	5	1	8	1	14	3
			3M	2	2	3	3	6	3	9	3	21	3	42	3

NOTE: a) Number of Propagating Modes ; b) Number of Modes used in Insertion Loss Evaluation.

Table 1. Number of Higher Order Modes in the Silencer.

The numbers of propagating modes for silencer 'M' and '3M' are given in Table 1. The modes that were included in the calculation of the insertion loss are also identified in the table for a representative sample of frequencies. It is seen that for multi-unit silencers the actual number of modes used is well below the total number of modes that are cut-on at a given frequency. The number of modes included in the calculation is seen to be similar for the two configurations of silencers represented in the table.

The insertion loss results for the various silencers tested are shown in Figures 3 through 6. Results for eighteen frequencies centered at 18 third octave bands from 100 Hz to 5000 Hz are presented in the figures.

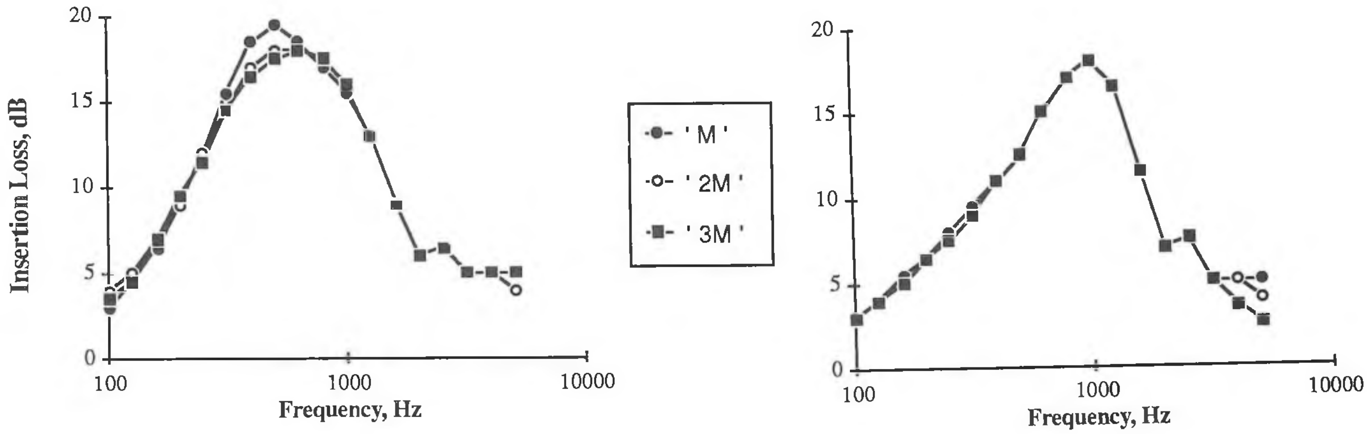

Figure 3. Insertion Loss of Splitter Silencers : M = 0.6 m, d / h =1 ;
a) R = 8000 MKS Rayls / m, b) R = 20000 MKS Rayls / m

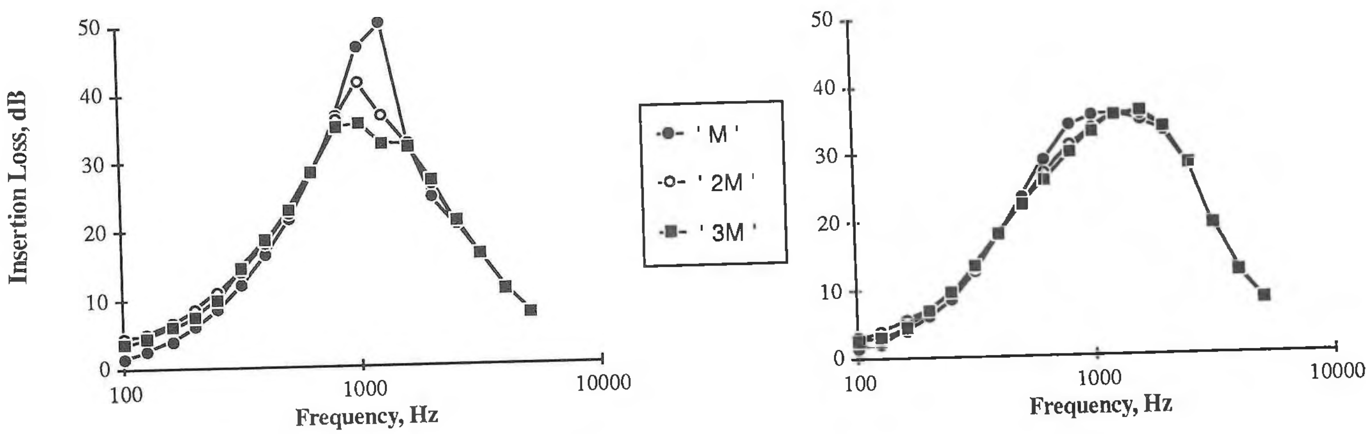

Figure 4. Insertion Loss of Splitter Silencers : M = 0.3 m, d / h =1 ;
a) R = 8000 MKS Rayls / m, b) R = 20000 MKS Rayls / m

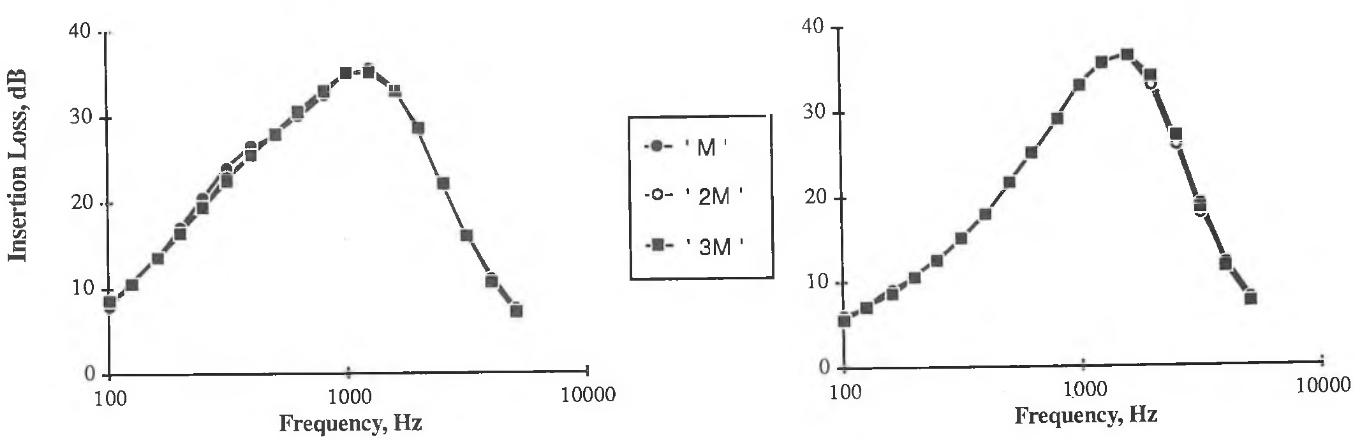

Figure 5. Insertion Loss of Splitter Silencers : M = 0.6 m, d / h =3 ;
a) R = 8000 MKS Rayls / m, b) R = 20000 MKS Rayls / m

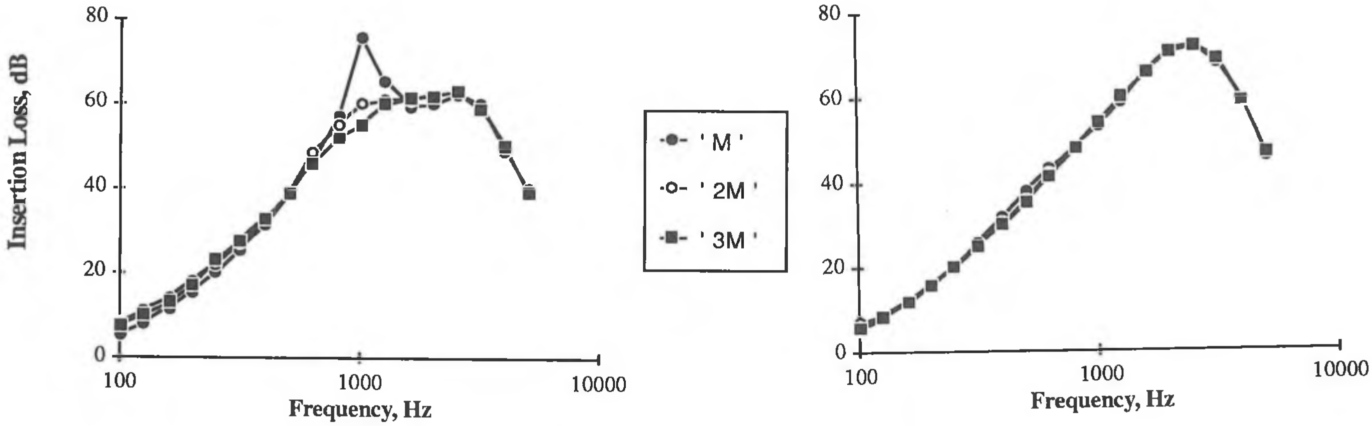

Figure 6. Insertion Loss of Splitter Silencers : M = 0.3 m, d / h =3 ;
a) R = 8000 MKS Rayls / m, b) R = 20000 MKS Rayls / m

The open-area percentage is 50 (d = h) for the results presented in Figures 3 and 4. The unit size is 0.6 m for Figure 3. It is seen from Figure 3 that there is hardly any difference between the insertion loss values for the three configurations.

A unit size of 0.3 m was used for the results shown in Figure 4. The insertion loss values for the three configurations are slightly different. One reason for this is that the influence of the absorbing material is more pronounced on the higher order modes in a smaller duct. The differences are within the predicted accuracy for most of the frequency bands. Large differences are seen in the results presented in Figure 4a for the light density material. The maximum difference is 11 dB at 1000 Hz; the difference is 17.5 dB at 1250 Hz. The predicted insertion loss is highest in the case of the single-unit silencer. This is due to the tuning of the silencer for the particular combination of frequency, material type (density is approximately 22 kg /cu.m.), unit size and open-area percentage. Outside the range of the tuning phenomenon, the deviations between the three configurations are well within the prediction accuracy.

The effect of increasing the material depth (d) is shown in Figures 5 and 6. The open-area percentage is 25 (d = 3 * h) for these results. The tuning effect is stll evident for the lighter material (Figure 6a). The maximum difference is 21 dB at 1000 Hz; the difference is 5.5 dB at 1250 Hz. The insertion loss values for the three configurations are remarkably similar to one another outside the 1000 Hz and 1250 Hz bands.

Finally, the complete octave band results are presented in Tables 2 to 5. The insertion loss results for the three configurations are very similar in all cases, with the exception of the cases summarized in Tables 3a and 6a for which differences of 7 dB and 6 dB occur at the 1000 Hz band.

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	4.5	11.5	19.0	15.0	7.0	5.0
2M	5.0	11.0	18.0	15.0	7.0	4.5
3M	5.0	11.5	17.5	15.0	7.0	5.0

a) Liner Flow Resistance = 8000 MKS Rayls / m

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	4.0	8.0	12.5	17.0	8.0	5.0
2M	4.0	7.5	12.5	17.0	8.0	4.5
3M	4.0	7.5	12.5	17.0	8.0	3.5

b) Liner Flow Resistance = 20000 MKS Rayls / m

Table 2. Insertion Loss of Splitter Silencers in Octave Bands, M = 0.6 m ; d / h = 1.0.

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	2.5	8.0	20.0	41.0	24.0	10.5
2M	5.5	11.0	21.0	37.5	24.5	10.5
3M	4.5	10.0	22.0	34.0	24.5	10.5

a) Liner Flow Resistance = 8000 MKS Rayls / m

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	2.5	8.5	21.5	35.0	31.0	11.0
2M	4.0	9.0	21.0	33.0	31.5	11.0
3M	3.0	9.0	21.0	32.5	31.5	11.0

b) Liner Flow Resistance = 20000 MKS Rayls / m

Table 3. Insertion Loss of Splitter Silencers in Octave Bands, M = 0.3 m ; d / h = 1.0.

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	10.0	20.0	28.0	34.0	25.5	10.5
2M	10.0	19.0	27.5	34.5	26.0	10.0
3M	10.0	19.0	27.5	34.5	26.0	10.0

a) Liner Flow Resistance = 8000 MKS Rayls / m

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	7.0	12.5	21.0	32.0	31.0	11.0
2M	7.0	12.5	21.0	32.0	30.5	11.0
3M	7.0	12.5	21.0	32.0	31.0	11.0

b) Liner Flow Resistance = 20000 MKS Rayls / m

Table 4. Insertion Loss of Splitter Silencers in Octave Bands, M = 0.6 m ; d / h = 3.0.

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	8.0	19.0	35.5	61.0	60.0	44.0
2M	10.5	21.0	37.0	58.0	61.0	43.5
3M	10.0	20.5	37.0	55.0	62.0	43.5

a) Liner Flow Resistance = 8000 MKS Rayls / m

Silencer Type	Insertion Loss, dB in Octave Bands with Centre Frequency, Hz					
	125	250	500	1000	2000	4000
M	8.0	19.0	35.5	52.0	69.0	51.0
2M	9.0	19.0	34.0	51.5	69.0	51.5
3M	8.0	19.0	33.5	51.5	69.0	51.5

b) Liner Flow Resistance = 20000 MKS Rayls / m

Table 5. Insertion Loss of Splitter Silencers in Octave Bands, M = 0.3 m ; d / h = 3.0.

4.0 Conclusions

Insertion loss predictions for splitter silencers were presented. The results of a parametric study based on unit size, material type, open-area percentage and frequency were shown. Results of an identical single-unit silencer were compared to the results of the splitter silencers. The comparison showed that there was hardly any difference in the insertion loss values for the three configurations of multi-unit silencers for all cases. The effect of tuning was highlighted. It can be concluded that the performance of splitter silencers can be evaluated from a single-unit silencer model with good accuracy.

Acknowledgement

The kind assistance of Ms. Valerie Chort, Review Engineer, Environment Ontario, in translating the abstract into French is greatly appreciated. We thank the editor for his helpful comments during the revision of the document.

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