Effect of Perforated Sheets on Rectangular Silencer Performance

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1.0 INTRODUCTION

HVAC duct silencers use porous materials such as glass wool, rock wool etc. to absorb the sound. Mathematical models for predicting the insertion loss of the silencers are a critical part of an optimum design and models to evaluate the insertion loss of absorptive rectangular silencers were developed by different researchers [1, 2]. The porous absorbers of the silencers are usually covered with a perforated sheet metal to protect the material from the main flow. Cummings [3] considered the effect of the perforated sheets and showed that the effect is usually negligible. The conventional prediction methods [4] therefore ignore the effects.

The effect of the perforated sheets is considered in this paper. The effect is included in the numerical model as a jump condition. The present results are limited to rectangular silencers only. Preliminary results of a parametric study is presented.

2.0 PERFORATED SHEET MODEL

The typical rectangular silencer consists of baffles with porous absorbers covered with perforated sheet metal and the main flow is confined to the open airway between two baffles. A cubic Galerkin finite element method [1] is applied to solve the equations governing the sound propagation in the rectangular duct. This method was chosen because it is easily extendable to aircraft engine nacelles with shearing airflow. The porous material is modelled as bulk reacting in the finite element method. The predictions include the effect of all propagating modes. The loss due to the absorbing material is used to approximate the insertion loss of the silencer. Further details concerning the model are described in Reference 1.

The finite element method applies two conditions, continuity of pressure and continuity of velocity across the absorbing material - open airway boundary. The perforated sheet metal provides a discontinuity across the material - open air way boundary. The sheet is treated as a limp sheet of finite surface density [4]. The pressure continuity is recovered for zero surface density. The continuity conditions are:

$$\begin{aligned} v_- &= v_+ \\ p_- - p_+ &= Z_p . v \end{aligned} \qquad (1)$$

where v_- and v_+ are the velocity across the boundary, p_- and p_+ are pressure across the boundary, and z_p is the acoustic impedance of the perforated sheets.

The impedance of the perforated sheets can be determined from the resonator design formulations of Ingard [5]. Maa [6] established a low frequency expression for the perforated impedance. Cummings [3] provides a general expression for the perforate impedance and is used in this paper. The perforated impedance is given by,

$$z_p = \frac{i k_0 z_0}{Q} \; [\, \delta \, (1 + \frac{z_a k_a}{z_0 k_0}) + d \,] \qquad (2)$$

where k_0 and k_a are the open air way and porous material wave numbers, z_0 and z_a are the open air way and porous material characteristic impedances, d is the thickness of the perforate, Q is perforate open area, and δ is the perforate mass end correction.

The end correction δ has been approximated for square and hexagonal array of holes by Cummings [3] using the theoretical curves of Ingard [5]. For square array of holes δ is given by,

$$\begin{aligned} \delta &= 0.850\, r_0 \,(1 - \frac{2.34 r_0}{l}), \quad 0 < \frac{r_0}{l} < 0.25 \\ \delta &= 0.668\, r_0 \,(1 - \frac{1.90 r_0}{l}), \quad 0.25 < \frac{r_0}{l} < 0.5 \end{aligned} \qquad (3)$$

where r_0 is the radius of perforate holes and l is the distance between the holes. The coefficients of 2.34 and 1.90 in Eq. (3) become 2.52 and 2.0 respectively for an hexagonal array of holes.

The boundary conditions given in Eq. (1) are appropriately entered in the finite element code and the insertion loss at any given frequency is evaluated from the attenuation rate of all the propagating modes.

3.0 RESULTS AND DISCUSSION

The finite element code was used to evaluate the attenuation rate for the plane propagating wave for a simple rectangular duct tested by Cummings [3]. The duct had two baffles of 5 cms thick with the 10 cm wide open air way. The porous material had flow resistance of 20,000 MKS Rayls per metre. The perforated sheet had a porosity of 14% and was 1.27 mm thick. The plane wave attenuation of Cummings [3] matched with the results of the finite element scheme. The above comparison was used as a test on the results of the finite element scheme.

Test data for a set of conventional rectangular silencers were available. The insertion loss results for three octave band of frequencies are presented in Table 1. The perforated sheets of the silencers were constructed from standard 22 gage sheet metal with the following properties: 0.853 mm thick, 23% open area, 2.38 mm diameter holes and the holes were staggered at 4.76 mm spacing. The results clearly show that the sheets used in conventional rectangular silencers had minimal influence on the insertion loss results even though the perforate open area was less than 40% for Cummings had predicted that sheets with open area less than 40% may drastically reduce the high frequency performance.

Perforate open area was varied for the standard 22 gage sheet metal perforates and the results are shown in Tables 2 and 3. The flow resistance of the porous absorber was 20,000 MKS Rayls for the results of Table 2 and the flow resistance of the absorber for the results of Table 3 was 8000 MKS Rayls. The thickness of the perforate sheet was 0.853 mm. It is seen that for the thin perforate sheet used for the parametric study, the effect with perforate open area is negligible both for the dense (20000 MKS Rayls) as well as for the loose (8000 MKS Rayls) porous absorber.

The perforate open area was set at 10% for the 2.76 mm diameter hole sheet and the thickness of the sheet was varied from 1 mm to 9 mm. The results are shown in Tables 4 and 5 for two different silencer overall width. The results for 0.305 m wide silencers are presented in Table 4 and the results for 0.610 m wide silencer are given in Table 5. The results show that the effects predicted by Cummings [3] are realised with thicker sheets with low perforate open areas. The performance at 1000 Hz and 4000 Hz octave bands reduce drastically with increasing thickness of the perforate sheets. The results seem to hold for the two sizes of the silencer sets. The drastic degradation in the performance of the silencers at high frequencies is true only with thick perforate sheets.

Additional parametric study is under way with hole diameter and results will be reported subsequently.

4.0 CONCLUSIONS

The effect of perforate sheets used in conventional rectangular silencers was studied and the results were presented in this paper. The sheets used in HVAC system silencers (0.853 mm thick sheets with 23% open area) were shown to have minimal impact on the acoustic performance of the silencers. The thin sheets, even with small open areas, had minimal influence on the overall performance. The study showed that perforate sheets degrade the high frequency performance of the silencers only if the sheets are reasonably thick.

REFERENCES

1. R. Ramakrishnan and W.R. Watson, "Design Curves for Rectangular Splitter Silencers," Applied Acoustics Journal, Vol. 35, 1-24 (1992).

2. R. A. Scott, "The Propagation of Sound between Walls of Porous Materials," Proceedings, Physical Society, London, Vol. 58, 358-368 (1946).

3. A. Cummings, "Sound Attenuation in Ducts Lined on Two Opposite Walls with Porous Material, with some Application to Splitters," Journal of Sound and Vibration, Vol 49, 9-35 (1976).

4. D.A. Bies, C.H. Hansen and G.E. Bridges, "Sound Attenuation in Rectangular and Circular Cross-Section Ducts with Flow and Bulk-Reacting Liner," Journal of Sound and Vibration, Vol 146, 47-80 (1991).

5. K.U. Ingard, "On the Theory and Design of Acoustical Resonators," Journal of the Acoustical Society of America, Vol. 25, 1037-1061 (1953).

6. D. Maa, "Microperforated-Panel Wideband Absorbers," Noise Control Engineering Journal, Vol. 29, 77-84 (1987).

Table 1. Insertion Loss Results in dB

		Insertion Loss, dB Octave Band		
Silencer Size	Condition	250 Hz	1000 Hz	4000 Hz
305 mm	No Perf	11	29	16
	Perf	11	29	16
457 mm	No Perf	13	29	7
	Perf	13	29	7
610 mm	No Perf	28	50	17
	Perf	28	50	17

NOTE: 22 gage perf. sheets (23% open area, 2.38 mm dia.)

Table 2. Silencer Insertion Loss with Perf. Open Area.

	Insertion Loss, dB in Octave Band		
Perforate Open Area	125 Hz	1000 Hz	4000 Hz
0.1	10	22	5
0.2	10	22	6
0.3	10	22	6
0.5	10	22	6

NOTE: Silencer is 610 mm wide, 203 mm thick baffles, 20000 MKS Rayls material, 0.853 mm thick perfs

Table 3. Silencer Insertion Loss with Perf. Open Area.

	Insertion Loss, dB in Octave Band		
Perforate Open Area	125 Hz	1000 Hz	4000 Hz
0.1	14	22	6
0.2	14	22	6
0.3	14	22	6
0.5	14	22	6

NOTE: Silencer is 610 mm wide, 203 mm thick baffles, 8000 MKS Rayls material, 0.853 mm thick perfs

Table 4. Silencer Insertion Loss with Perf. Thickness.

	Insertion Loss, dB in Octave Band		
Perforate Thickness	125 Hz	1000 Hz	4000 Hz
1 mm	10	22	5
3 mm	10	20	8
5 mm	10	17	6
7 mm	10	15	4
9 mm	10	13	2

NOTE: Silencer is 610 mm wide, 203 mm thick baffles, 20000 MKS Rayls material, 10% open perfs

Table 5. Silencer Insertion Loss with Perf. Thickness.

	Insertion Loss, dB in Octave Band		
Perforate Thickness	125 Hz	1000 Hz	4000 Hz
1 mm	15	38	26
3 mm	15	37	22
5 mm	15	32	13
7 mm	15	27	7
9 mm	15	21	4

NOTE: Silencer is 305 mm wide, 102 mm thick baffles, 20000 MKS Rayls material, 10% open perfs