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The Effects on Acoustic Characteristics of Aircraft with Constrained Layer Damping

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Abstract. The constrained layer damping(CLD) could suppress vibration and sound radiation of thin-walled structure like aircraft fuselage. By calculating the sound transmission loss of panel with CLD based on finite element analysis method and sound pressure level of aircraft with CLD based on statistical energy analysis method, and compared with experimental results from standing wave tube and reverberation-anechoic chamber, the acoustic characteristics of aircraft and panel with CLD and the effect of CLD's parameters such as density and coverage have been investigated. The experimental and simulation results show good consistency and trend.

Keywords: acoustic, constrained layer damping, aircraft.

1. Introduction

As an important competitive factor for civil aircraft, cabin noise level affects the comfort and communication for pilots and passengers. How to improve the cabin acoustic environment has become a hot topic for civil aviation research. The noise of aircraft is mainly air-borne noise and structure-borne noise. For noise treatment, insulation blanket which made up of porous fiberglass material could absorb air-borne noise in mid-high frequency. But it is difficult to suppress the structure-borne noise in low-mid frequency which is usually generated by engine and fuselage structure vibration, especially in the limit of weight and space for civil aircraft design.

The constrained layer damping (CLD) is a typical material extensively applied to suppress vibration and sound radiation for thin-walled structure in automobile, subway, aviation and so on[1]. Foreign and domestic researchers have done much work on testing and analyzing CLD's mechanic characteristics, vibro-acoustic characteristics and optimization by analytic method[2, 3], numerical method[4, 5] and test method[6]. These work most focus on vibration suppression and sound radiation of beam or panel structure with CLD.

This paper aims to investigate the acoustic characteristics of aircraft with CLD and the effect of CLD's parameters such as density and coverage. First, a finite elements analysis(FEA) model for panel with CLD has been established to estimate sound insulation characteristics and compared with standing wave tube measurement. Then acoustic characteristics of aircraft panel with different types of CLD have been tested and analyzed. Lastly, acoustic characteristics of an engine tail suspended aircraft with different CLD have been investigated by statistical energy analysis(SEA) method.

2. Sound Insulation of CLD

2.1. Structure and parameters of CLD

Figure 1 shows a typical composite structure that CLD is attached on substrate. This composite structure is made up of constrained layer, elastic-viscoelastic layer and substrate layer.

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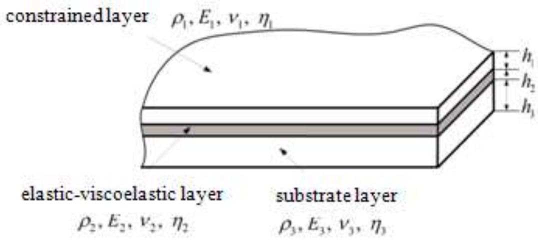


Fig. 1: Typical schematic constrained layer damping structure.

The material parameters of two typical types of CLD are listed in Table 1. The areal density of CLD1 is 2.2 kg/m^2, CLD2 is 4.0 kg/m^2.

Table 1: Physical parameters of two types of constrained layer damping

	Parameters	CLD1	CLD2
Constrained layer	Density ρ_1 / kg/m^3	2700	2700
	Young's modulus E_1 /GPa	69	69
	Poisson ratio ν_1	0.3	0.3
	Loss factor η_1	0.001	0.001
	Thickness h_1 /mm	0.3	0.9
Elastic-viscoelastic layer	Density ρ_2 / kg/m^3	1300	1300
	Young's modulus E_2 /MPa	5.5	5.5
	Poisson ratio ν_2	0.4	0.4
	Loss factor η_2	0.3	0.45
	Thickness h_2 /mm	1.4	1.0

2.2. Structure and parameters of CLD

The sound transmission loss of the two CLD attached on aluminium substrate(100% coverage) has been tested through standing wave tube via ASTM E2611-09[7]. The inner diameter of the standing wave tube is 228 mm and the diameter of test sample is 225 mm. Bigger standing wave tube gives lower frequency test results more accurately, but the cut-off frequency is also lower. The measurement setup is shown in Figure 2.

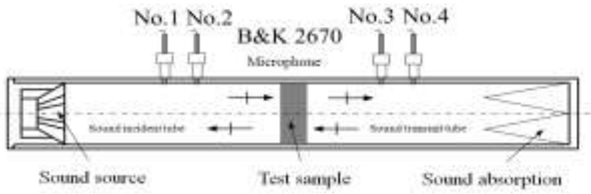


Fig. 2: Schematic of the sound tube measurement setup.

Figure 3 shows the sound transmission loss(TL) of three test samples. All curves have regular fluctuations above 900 Hz, it is because incident sound wave induce the standing wave caused by the tube's own modal. Although the effective frequency band of this standing wave tube is 68.6 Hz ~ 881.6 Hz, the TL curves will also reflect the sound insulation capability of these test samples besides this frequency band.

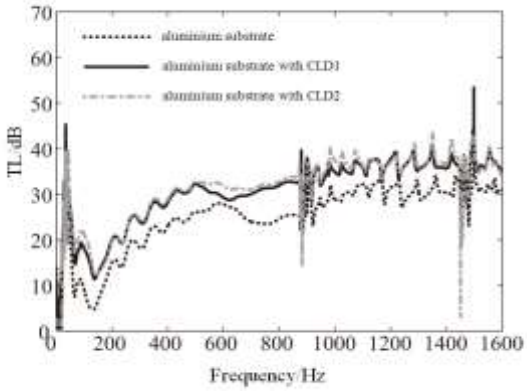


Fig. 3: Comparison of experimental TL results in sound tube.

Due to the higher total loss factor of the composite structure and mass effect by CLD, the TL increases 3 dB ~ 5 dB after attaching CLD compared with only aluminium panel.

2.3. FEA model of CLD

The FEA model of CLD for TL calculation has been built up, shown in Figure 4. The boundary condition of the composite panel is simply supported. TL is calculated according to incident and transmitted sound energy.

$$\mathrm{TL} = 10\log_{10}\left(E_{\mathrm{i}}/E_{\mathrm{t}}\right) \tag{1}$$

E_i is incident sound energy and E_t is transmitted sound energy.

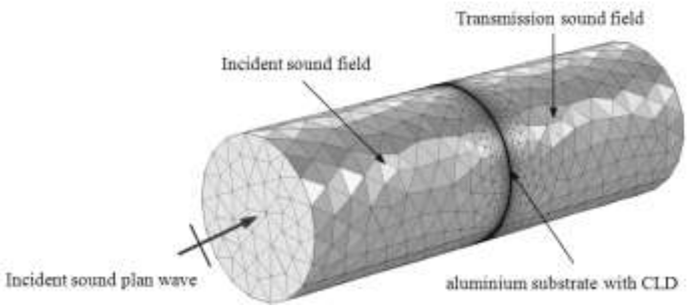


Fig. 4: Finite element model for TL calculation.

For the case of CLD2, FEM and experimental results are shown in Figure 5. The data shows that the calculated result has good agreement with the test. Amplitude of peak and valley at several frequency is different because the sealing grease used in the standing wave tube test has much damping. The TL peaks at position B and D is the anti-resonance phenomena, while the TL valleys at position A, C and E is the resonance phenomena of composite panel.

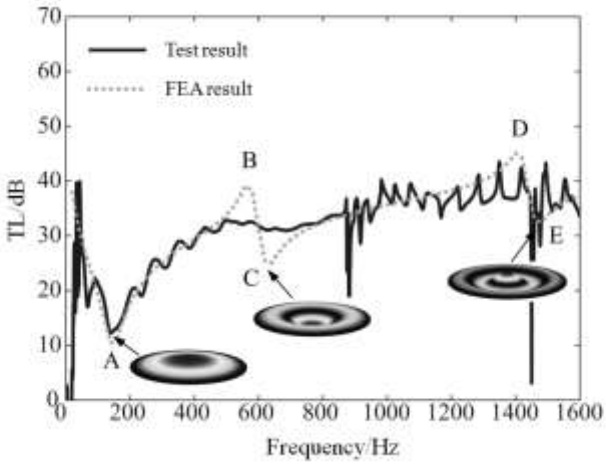


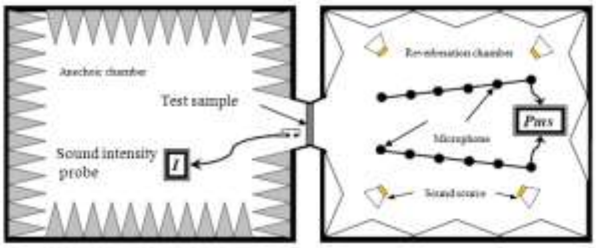
Fig. 5: Comparison of FEM and experimental results for the case of CLD2.

3. Acoustic Characteristics of Aircraft Panel

3.1. Sound insulation of aircraft panel

In reverberation-anechoic chamber, the TL of an aircraft panel which length 540 mm, width 535 mm and thickness 1.2 mm with different CLD and insulation blanket has been measured via ISO 15186-1-2000[8]. Measurement picture and setup are shown in Figure 6.

(a) (b) (c)



(d)

Fig. 6: Sample of the aircraft panel and TL test devices in reverberation-anechoic chamber
(a) aircraft panel (b) attached CLD (c) attached insulation blanket (d) schematic of the TL test.

The test configurations are listed in Table 2. Figure 7 shows the TL of five test configurations. Compared with configuration 1(aircraft panel with only 3 inch insulation blanket), the TL increases 3 dB ~ 5 dB after attaching different CLD at 250 Hz ~ 1600 Hz. For the same areal density, TL of aircraft panel with 30% CLD coverage is nearly 1.5 dB less than 45% CLD coverage. Below 250 Hz, aircraft panel with large areal density CLD has higher TL than small areal density CLD. Because below aircraft panel's first resonance frequency, nearly 250 Hz is "stiffness controlled area". For 315 Hz ~ 1250 Hz, TL of aircraft panel with three different areal density CLD shows no obvious difference. Because above aircraft panel's first resonance frequency is "mass controlled area", the CLD's mass is in a very small proportion for the total mass of the composite panel. However, For 1250 Hz ~5000 Hz, TL of aircraft panel with large areal density CLD is lower than small areal density CLD. The possible reason is that thick constrained layer increases the composite panel's sound radiation efficiency, the mechanism needs further investigation.

Table 2: Configurations description of aircraft panels

Name	Configuration 1 description
Configuration 1	aircraft panel + 3 inch insulation blanket
Configuration 2	aircraft panel + CLD(2.2 kg/m^2, 45% coverage) + insulation blanket(3 inch)
Configuration 3	aircraft panel + CLD(3.0 kg/m^2, 45% coverage) + insulation blanket(3 inch)
Configuration 4	aircraft panel + CLD(3.0 kg/m^2, 30% coverage) + insulation blanket(3 inch)
Configuration 5	aircraft panel + CLD(4.0 kg/m^2, 45% coverage) + insulation blanket(3 inch)

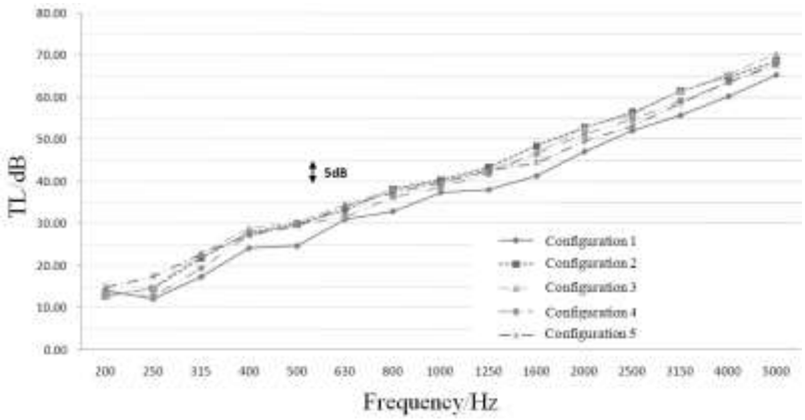


Fig. 7: Comparison of experimental TL results in reverberation-anechoic chamber.

3.2. Vibro-acoustic characteristics of aircraft panel

The vibro-acoustic characteristics of aircraft panel with CLD1 have also been tested. One vibration exciter and three acceleration sensors have been put at the back of aircraft panel(facing reverberation chamber), shown in Figure 8. Sound intensity is measured at the front side of aircraft panel(facing anechoic chamber).

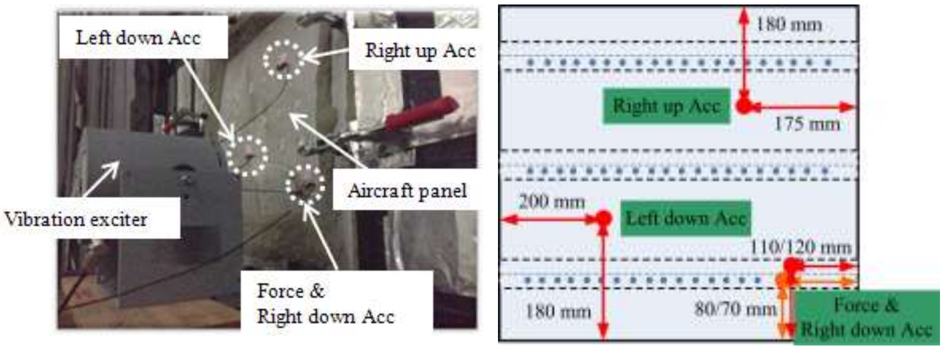


Fig. 8: Vibro-acoustic measurement setups on site.

Excite white noise force, take logarithm(reference 1 $m/s^2/N$) for the ratio of acceleration signal to excitation signal, the vibration transfer thus amplitude frequency response of left down position is shown in Figure 9. After attaching CLD, the amplitude of resonance peak is greatly weakened.

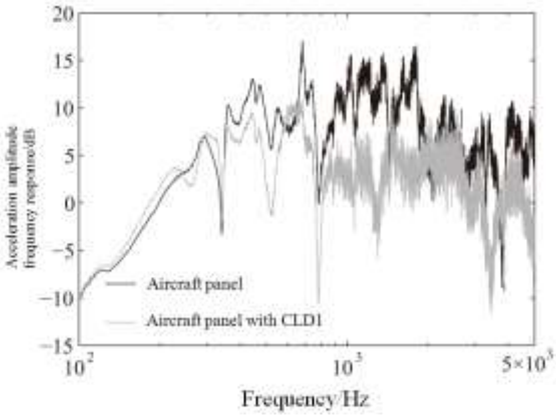


Fig. 9: Vibration transmission characteristics of the aircraft panel.

The sound intensity level(reference 10^{-12} W) is shown in Figure 10, it is similar to the TL inversion curve. Compared with only aircraft panel, the sound intensity level reduce 3 dB ~ 5 dB for the interested frequency band after attaching CLD.

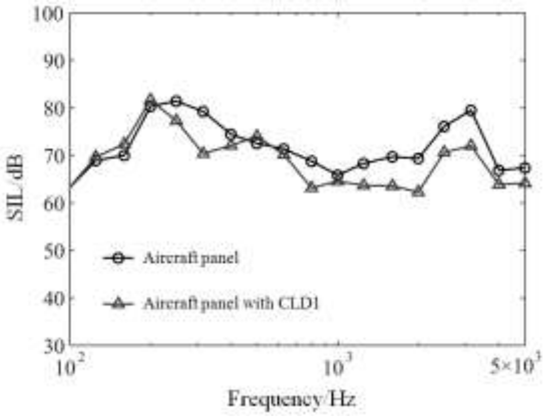


Fig. 10: Acoustic radiation characteristics of aircraft panel under vibration excitations.

4. Acoustic Characteristics of Aircraft

FEA is very suitable for deterministic structures at low-mid frequency. While at higher frequency, the structure vibration modal becomes very dense, and a large number of degrees-of-freedom is required for accurate analysis response. This makes the calculation time and computing space huge, especially if the analysis objective has complex structures. SEA is developed to solve the acoustic analysis in full audio frequency range of larger structures such as aircraft.

In order to analysis the difference of FEA and SEA calculation results, both FEA and SEA models for a aluminium panel have been built up, shown in Figure 11.

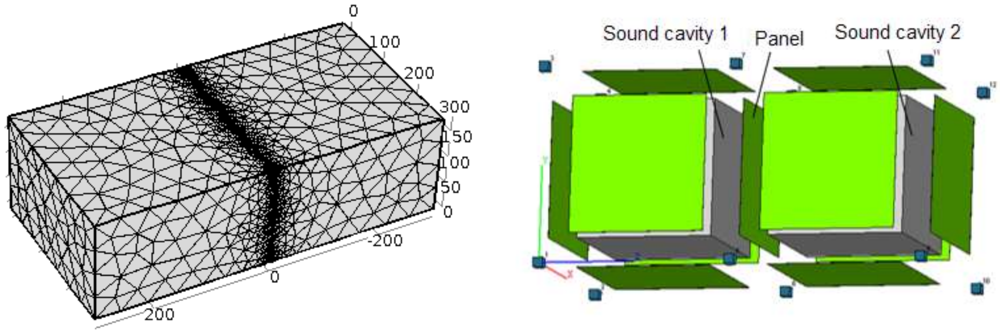


Fig. 11: FEA and SEA model of aluminium panel for TL calculation/

The calculated TL is shown in Figure 12. SEA result is more smooth, it couldn't reflect the TL peak and valley caused by structure modal as accurate as FEA result. Since the overall trend is consistent, SEA model could be used to predict the overall acoustic characteristics.

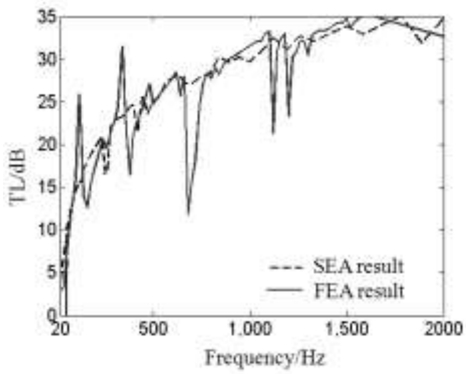


Fig. 12: Comparison of FEA and SEA results of aluminium panel.

The SEA model for an engine tail suspended aircraft founded in VA One software is shown in Figure 13. This model has been validated by flight test. The modelling and validating process is not described here[9].

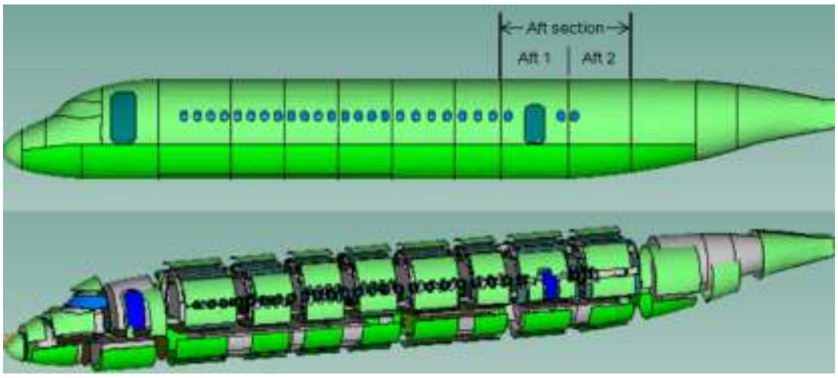


Fig. 13: SEA model of a engine tail suspended aircraft.

Engine tail suspended aircraft usually has noise issue in after section. According to test and analysis, the main noise sources of after section are engine fan noise and structure-borne noise caused by the vibration of engine mounts. So CLD is considered to use to reduce cabin noise in after section.

Figure 14 shows the predicted third octave sound pressure level(SPL) of after section with different coverage CLD1. The predicted overall SPL is listed in Table 3. Attaching CLD on the aircraft after section fuselage skin is a effective way to reduce noise. The cabin noise of after section could be reduced 3.2 dBA by attaching 45% coverage CLD1, the acoustic performance of 45% coverage CLD1 is better than 30% coverage. It is consistent with the sound insulation test results of aircraft panel.

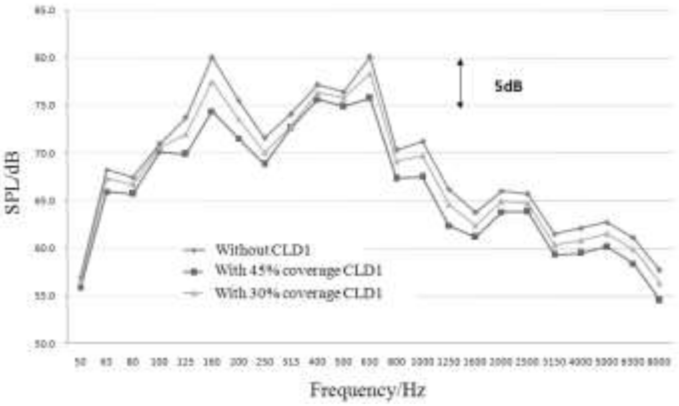


Fig. 14: Comparison of predicted third octave SPL with different coverage CLD1.

Table 3: Predicted overall SPL with different coverage CLD1

	Without CLD1	CLD1 45% coverage	CLD1 30% coverage
Predicted SPL / dBA	83.7	80.5	82.2
Noise reduction / dBA	/	3.2	1.5

5. Conclusions

In this paper, the acoustic models of aircraft and panel with CLD have been established based on FEA method and SEA method to analyze the acoustic characteristics. FEA model is suitable for analyzing sound insulation and vibro-acoustic characteristics of CLD while SEA model is suitable for analyzing the acoustic characteristics of aircraft. The sound transmission loss test results from standing wave tube and reverberation-anechoic chamber and simulation results have good consistency and show that CLD could reduce the cabin nose of aircraft effectively.

Furthermore, the effects of CLD's parameters such as areal density and coverage on the acoustic characteristics of aircraft have been investigated. The results show that coverage is a more critical parameter than areal density for the noise reduction of CLD. For typical noise reduction application, the optimal CLD design with better performance and less weight could be realized quickly.

In further study, the optimization of CLD application for acoustic characteristics will be investigated by parameters, installation location and coverage.

6. Acknowledgements

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