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EXPERIMENTAL STUDY OF THE AIRCRAFT ENGINE DUCT COMBINED LINERS

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Abstract

Experience of civil aircraft noise reduction up to requirements ICAO Annex 16 Chapter 4 has shown that the most effective engine noise reduction method is fan ducts treatment with broadband liners. So far single layer honeycomb liners are applied on a lot of engines. To increase liner width frequency band are applied two layer honeycomb liners. For this purpose flat models of the two-layer combined liners have been tested with the double reverberant chamber. The tested liners design differed from conventional two layer honeycomb liner with the internal layer. The porous homogeneous layer was used instead of a honeycomb one.

This material consists of silica fibers of average diameter 9 μm. It has porosity not less than 90 %. The maximal temperature of operation of this fibrous material makes up 1100ºC, the density can vary from 150 up to 400 kg / m3.

It was shown that acoustic efficiency of the two-layer combined liner is close to the two layer honeycomb liner of equal thickness. Owing to high acoustic efficiency of the porous layer on the wide frequency band the combined liner loses resonant properties of the acoustic response. In this case external to the duct flow the honeycomb layer for the porous layer can play a role of protection from influence high-speed turbulent flow. Thus combined two-layer liners can appear preferable at cost, weight, and operational adaptability to manufacture in comparison with conventional two layer honeycomb liners.

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1. INTRODUCTION

Single layer honeycomb liners have found a wide application in aviation engines for fan noise reduction in the 1970s. Most aircraft equipped with turbofans satisfied ICAO Annex 16 Chapter 3 requirements due to the reduced fan tip speed and installation of the sound absorbing liners into the intake and fan ducts. The single layer honeycomb liner falls in a resonance type of the noise suppressors. Their performance usually has a high value of noise attenuation over about one octave frequency bandwidth. Further engine noise reduction has been reached by using double layer honeycomb liners.

The comparison of the single and double layer honeycomb liner performance equal thickness shows that the insertion loss maximum of the single layer liner response maybe somewhat higher than that of the double layer one. However in terms of effective perceived noise level (EPNdB) used for aircraft certification the double layer liners are more acoustic effective than the single layer one. The reason is that the double layer liner has more uniform performance over 1.0 – 6.3 kHz frequency range. In this frequency range the human ear has the greatest annoyance that is taken into account at aircraft noise prediction in the far field. The apparent advantage of the single layer liner response in a narrow frequency band hardly possible to use in practice as an engine operates at various rotation speed, and tonal fan noise components are displaced in frequency. The double layer liner has more uniform attenuation performance, therefore it has more acoustic efficiency at cumulative assessment of noise level.

The attempts to apply the bulk porous absorbers with a high acoustic efficiency and a wide bandwidth were repeatedly made earlier. Unfortunately, imperfections are inherent in this type of the liners, interfering introduction into practice: a small resource, rather low operational qualities and low fire resistance. The small resource of the bulk liners is due to fast weariness of fibers, which are under a highly intensive sound field impact. This causes the gradual destruction of the fibers into fine fragments that are blown with turbulence air flow. The low operational qualities are connected with the fast pollution of a porous surface and difficulties of its cleaning. At last, bad fire-prevention properties even for high-temperature and fireproof volumetric materials are explained by their ability to keep hydrocarbons in the quantities considerably exceeding a body weight of bulk liners. Therefore, practical using of such materials demands the progressive solution of these problems. In the given work the attempt to come closer to the solution of these problems has been done.

The heat protection material called TZM-23 was tested as a bulk porous sound absorbing material. This material (TZM-23) based on silica fiber and boron-containing sintering additive has been investigated with the aim to manufacture specimens of sound-absorbing structures. The process of the material production involves vacuum forming of the articles of specified shape and size followed by drying and firing. One of tested sets was manufactured using additional impregnation with the 2 % silica sol aqueous solution.

Its skeleton consists of silica fibers of average diameter equal to 9 microns. It has porosity not less than 90%. The maximal operational temperature of this fibrous material makes up 1,100ºC, the density can varies from 150 up to 400 kg/m^3. The material durability depends on density and is equal 0.5-3.0 MPa at compression and 0.9-4.0 MPa at bending.

2. TEST FACILITY

The facility is designed for study of acoustic liners efficiency [1, 2]. The test facility consists of two reverberant chambers connected by a rectangular duct, a powered sound source, and an air auxiliary compressor (Figure 1). The conditions close to the ones in the turbofan ducts (highly intensive sound and high-velocity air flow) are simulated in the test duct. An air siren generating sound power levels up to 160 dB is used as a highly intensive source. The duct walls can be treated with a sound absorber, and the auxiliary compressor can supply air flow in any direction – forward and backward.

The liner response is defined by comparison of transmission losses of the hard and treated duct walls.

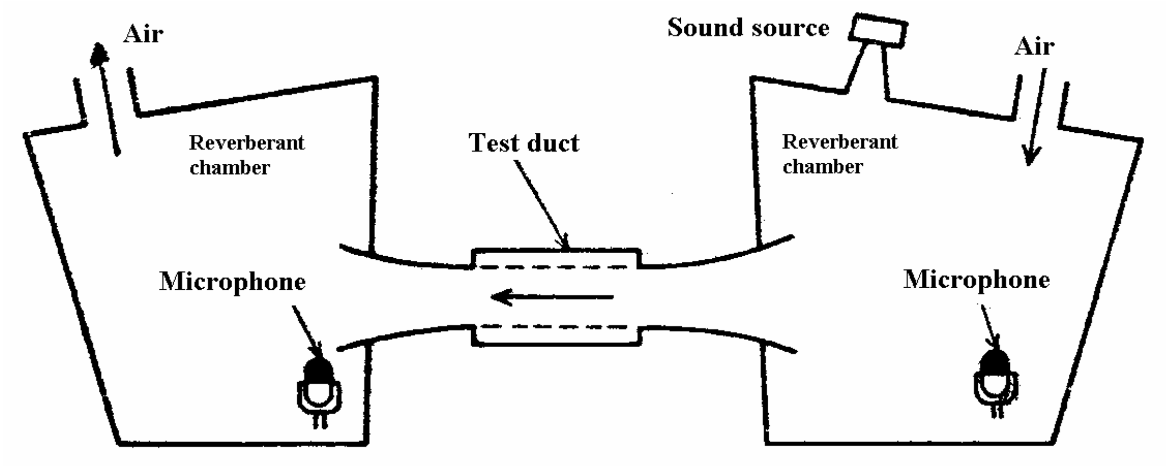

Figure 1. Double reverberant chamber test facility scheme

The power reduction spectra under test duct conditions may be measured with high accuracy by using the reverberant energy technique if the diffuse field conditions exist in both chambers of the test facility. The duct cross-sectional perimeter should be rather small to keep the sound field in the reverberant chamber diffuse. On the other hand, it should be large enough to maintain low resistance of the duct hole for sound propagation from the source chamber to the receiver chamber. In fact, the perimeter should be larger than the maximal wave length of the operating frequency range. Then, the liner acoustic efficiency (i.e. insertion loss-IL) is determined at the given frequency as

$$IL = (L_S - L_R)_{liner} - (L_S - L_R)_{hard} ,$$

where L_S , L_R – sound pressure level in the source and the receiver chamber, respectively.

3. EXPERIMENTAL PROCEDURE AND TESTED LINER SAMPLES

The following measurements are performed under any operating conditions:

- sound pressure levels in both the source and receiver reverberant chambers,
- static and total pressure in the duct for Mach number definition,
- rotational frequency of the siren by an impulse probe,
- siren inlet pressure.

Sound pressure level is measured in the source and receiver reverberant chambers over a 100…20000 Hz -frequency range at sound intensity up to 160 dB and Mach number M=0.0; (minus) - 0.25, i.e. sound and air flow in the test duct propagate in opposite directions as in the intake.

The cross section of the test duct with hard walls is set forth as 250x250 mm. Four test samples were installed along one duct wall at a length of 1 m. Thus, the intake compartment was simulated.

Two liner responses characterizing the tonal and broadband noise reduction are estimated during data processing. The tonal noise is determined over a 500…12500 Hz frequency range by tuning the rotational frequency of the siren. The liner response features an insertion loss of the sound power and can be considered as the liner efficiency.

The liner set involved four flat samples with dimensions 400×250×h (mm). Five liner sets containing a layer of the TZM-23 porous material were tested in the model duct of the double reverberant chamber facility (Table 1).

Table 1. Liner design parameters.

Set #	Total thickness, mm	First layer	Second layer
1	15	P=40%; TZM-23; h=15 mm (with impregnation)	
2	15	P=40%; TZM-23; h=15 mm	
3	30	P=40%; TZM-23; h=30 mm	
4	40	P=10%; honeycomb; h=20 mm	TZM-23; h=20 mm
5	30	P=10%; honeycomb; h=10 mm	TZM-23; h=20 mm

The liner sets 1-3 represent the single-layer liner of a bulk porous material covered with acoustic transparent face sheet (Figure 2). The liner sets 4-5 represent the double-layer liner. The first layer consists of a perforated plate and honeycomb cells. The second layer is a bulk porous material (Figure 3).

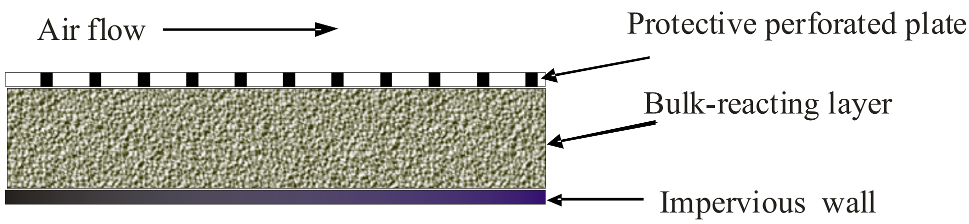

Figure 2. Single-layer liner design

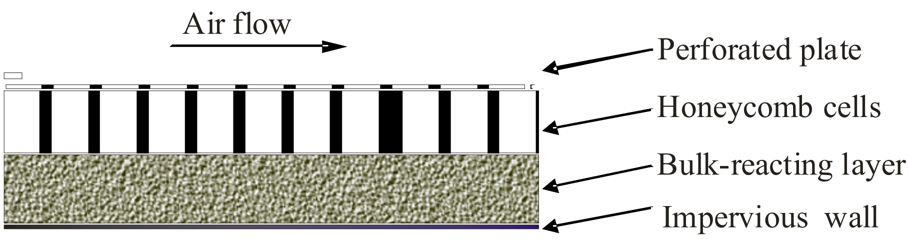

Figure 3. Double-layer liner design

The samples density was changed from 185 to 250 kg/m^3. 15 mm-thickness samples of one set were impregnated with a 2 % silica sol aqueous solution protecting a surface layer against destruction. After impregnation the average density of samples has increased up to 265 kg/m^3.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The total performance of the liner is taken as value Σ determined by average insertion loss over a frequency range from 1,000 to 6,300 Hz (IL) and standard deviation (δ) for tonal and broadband noise separately. The liner having a higher insertion loss and simultaneously more uniform performance is more acoustically effective.

$$\Sigma = (IL_t - \delta_t) + (IL_b - \delta_b)$$

Index «t» denotes the tonal noise component, index «b» – the broadband component.

The performance of five tested liners is presented in Table 2.

Table 2: Performance of tested liner efficiency (dB)

Set #	IL_t	δ_t	IL_b	δ_b	Σ
1	3.82	0.78	3.98	0.93	6.09
2	3.99	0.87	3.53	1.55	5.10
3	4.05	0.54	5.08	1.76	6.83
4	4.24	1.53	4.34	1.92	5.13
5	3.62	0.65	4.07	1.25	5.79

The insertion loss of three bulk-reacting single-layer liners is presented in Figure 4. It is seen that single-layer liner containing material TZM-23 efficiently reduces noise over a wide frequency band. The insertion loss of the bulk-reacting single-layer liners averages 3.8 dB (#1) – 4.0 dB (#3) over the 1.0-6.3 kHz frequency band. The maximal insertion loss lies in the 630-3150 Hz frequency band. Tests have confirmed that the insertion loss of a bulk-reacting single-layer liner increases with increase in thickness.

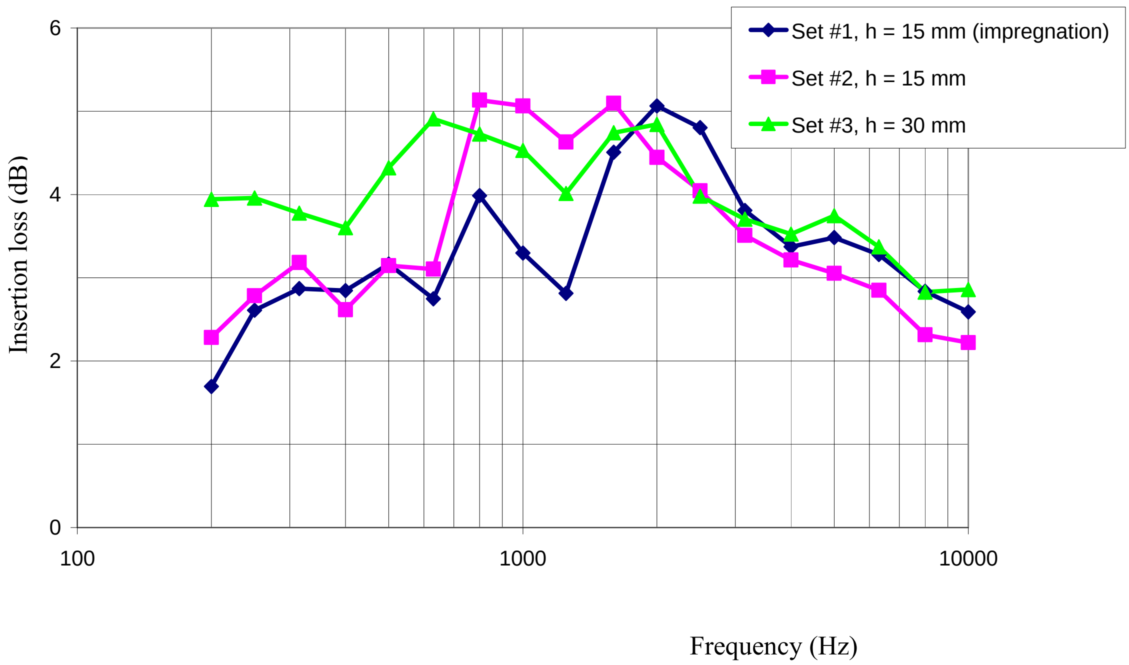

Figure 4. Acoustic efficiency of single-layer porous liners

It was interesting to compare acoustic characteristics of the bulk and honeycomb liners (Figure 5). Let us note that the honeycomb liners have higher efficiency than the bulk ones over a narrow frequency band. However this advantage can hardly be realized in practice as the noise liner should mainly suppress peak components but the tonal fan noise at blade passing frequency changes within the limits of some octaves. The predicted total efficiency of the bulk liner is found to be higher than that of the honeycomb one with relation to the aircraft certification according to the ICAO Annex 16.

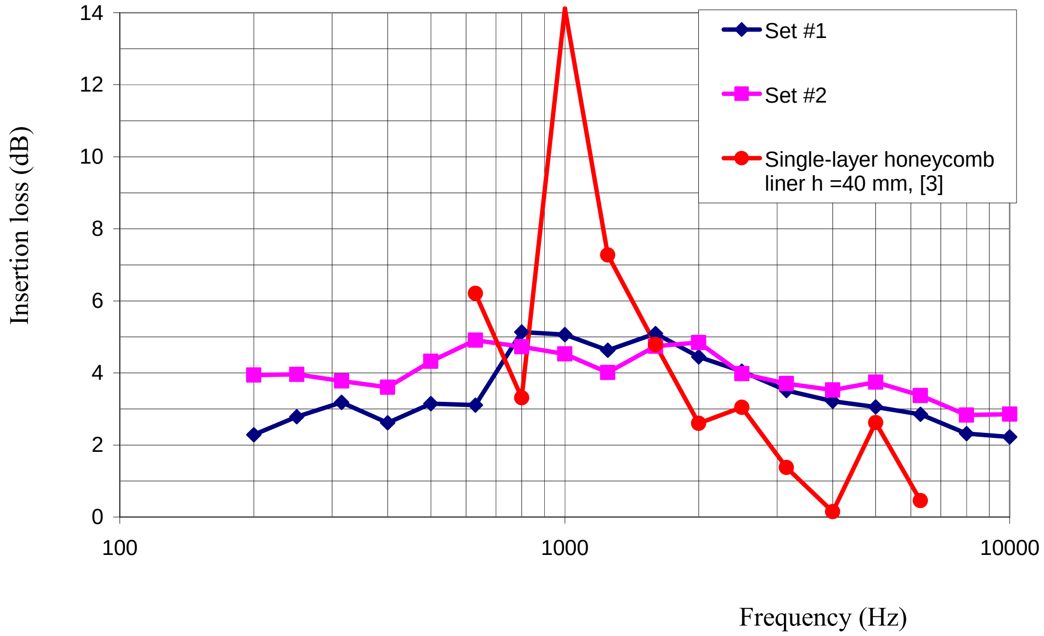

Figure 5. Acoustic efficiency of the bulk and honeycomb liners

Double-layer combined liner is composed of perforated facesheet, honeycomb structure and inner porous material layer (Figure 3). It was possible to assume that honeycomb and porous layers will equally contribute to the insertion loss value. On the other hand, there are no physical reasons to obtain more acoustic efficiency of the combined liner in comparison with a single-layer porous liner. Presented in Table 2 total value Σ confirmed the second assumption. The insertion loss performance of combined liners also shows that the contribution of the honeycomb layer having thickness 10 mm (set #4) is less than the contribution of the 20 mm layer (set #5). (Figure 6).

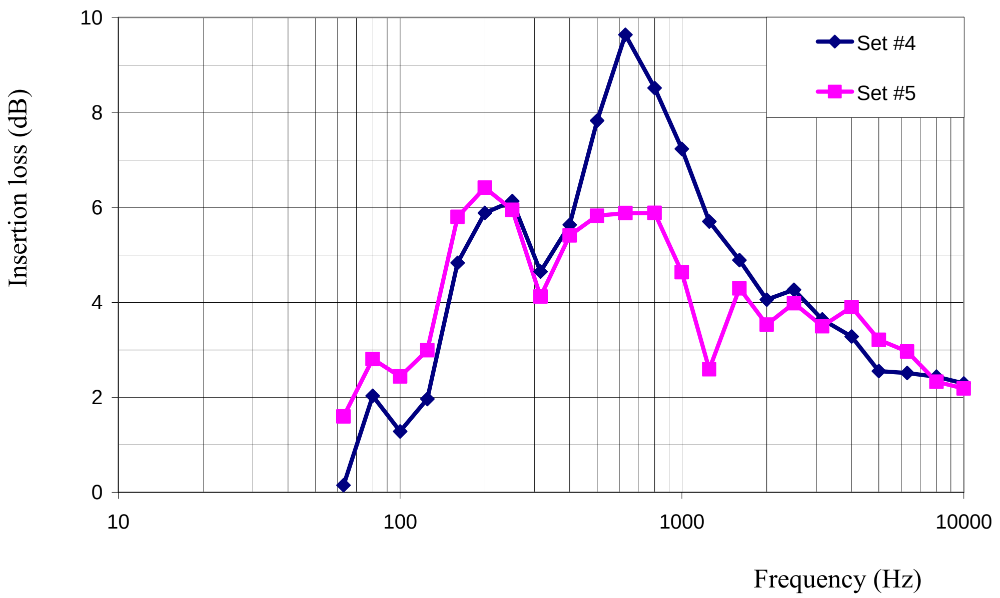

Figure 6. Combined liners insertion loss when honeycomb layer thickness is 10 mm and 20 mm

The comparison of the insertion loss performance of the double-layer honeycomb (h=45 mm) and combined (h=40 mm) liners obtained in identical conditions is shown in Figure 7.

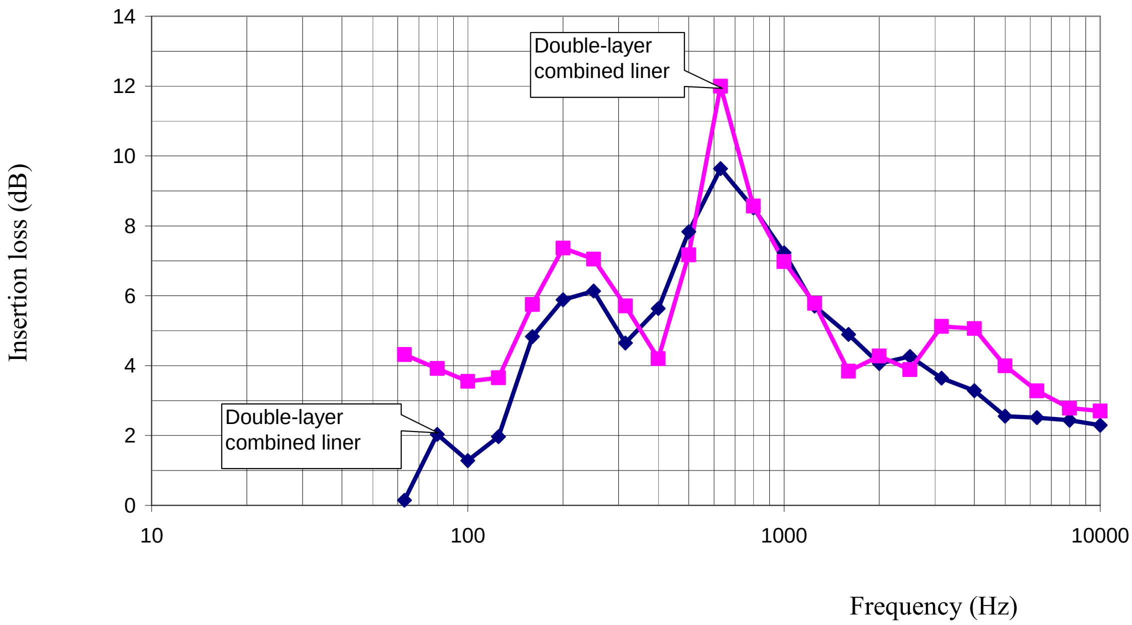

Figure 7. Double-layer honeycomb (h=45 mm) and combined (h=40 mm) liners insertion loss. M = – 0.245

It turns out that these responses are similar. Their difference implies that due to presence of a porous layer the combined liner response losses the resonant properties. But the bulk liner placed under cavity resonator has the high sound absorption. In fact, the first layer of the double-layer combined liner neighboring the air flow protects the porous layer from air flow action in an aircraft intake.

6. CONCLUSIONS

1. The combined liners at least do not lose acoustic efficiency in comparison with the conventional honeycomb liners, but can have advantages in weight, cost and operational properties.
2. As porous material TZM-23 has good structural and long durability, it can find application in various suppressor systems of the aviation engines, stationary turbo machines and aircraft auxiliary power plants.

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