Evaluation of sound absorbing performance of CFRP acoustic panel prototype formed using media blasting

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Abstract. Sound absorbing structures (acoustic panels) are used for reducing the noise of aircraft engines. They typically comprise a honeycomb core bonded to an aluminum plate, which contains numerous small-diameter holes in a dense array. While numerous aircraft structures are being replaced with carbon fiber reinforced plastics (CFRP) for weight reduction, this material has not yet been applied to sound absorbing panels. We developed a media blasting method and used it to form a large number of small-diameter holes in a CFRP plate, and no delamination. We made CFRP sound absorbing panels using these plates and measured the normal-incidence sound absorption rate with an impedance tube. The result confirmed that the CFRP panel had good sound absorbing performance. We then fabricated a large 1-m-square sound absorbing panel by adhesive assembly and measured its sound absorbing performance in a reverberation room. Good sound absorbing performance was demonstrated.

Introduction

In aircraft engines, a sound absorbing structure is provided in the inner wall of the engine cowl to reduce noise, both at airports and in flight. The typical sound absorbing structure is a sandwich panel in which a resin or aluminum honeycomb core is bonded to an aluminum plate or a glass fiber reinforced polymer plate perforated with densely packed small holes 1 to 2 mm in diameter on one side to form Helmholtz resonators (Fig. 1). If the small hole diameter is 2 mm and their pitch is 4 mm, the number of holes in a panel with an area of 1 m^2 is about 60,000. Assuming that the panel size required for a large aircraft is 10 m^2, the total number of holes is 600,000. For purposes of reduced weight, increased strength, corrosion prevention, and heat insulating performance, many aircraft structural parts are being replaced with carbon fiber reinforced plastics (CFRP). However, they have not yet been applied to functional members such as sound absorbing structures. Among the reasons are that the CFRP material is expensive, the processing cost is high, and for complicated and small parts the merit of material change is less cost-effective. Furthermore, in the sound absorbing structure, mass-production of holes is necessary, but when CFRP is perforated with a conventional drill or punch, tool wear and damage are heavy, tool cost is high, and quality problems such as material delamination and cracking occur. However, the authors have developed a method using media blasting to form small-diameter holes, making it possible to produce a large number of densely packed small holes with high efficiency and low cost in thin CFRP plates, without delamination defects [1].

Using this technique, we made various sound absorbing panels by creating a large number of holes in CFRP plates using media blasting technology and bonding it with a honeycomb core [2]. Next, a test piece was cut out from the sound absorbing panel and the normal incident sound absorption rate was measured with an impedance tube, and it was confirmed that the CFRP panel had good sound absorbing performance. Furthermore, in a similar manner, a large

1-m-square sound absorbing panel was fabricated and assembled, and the sound absorbing performance of this panel was measured using a reverberation room. It was confirmed that the panel exhibited good sound absorbing performance.

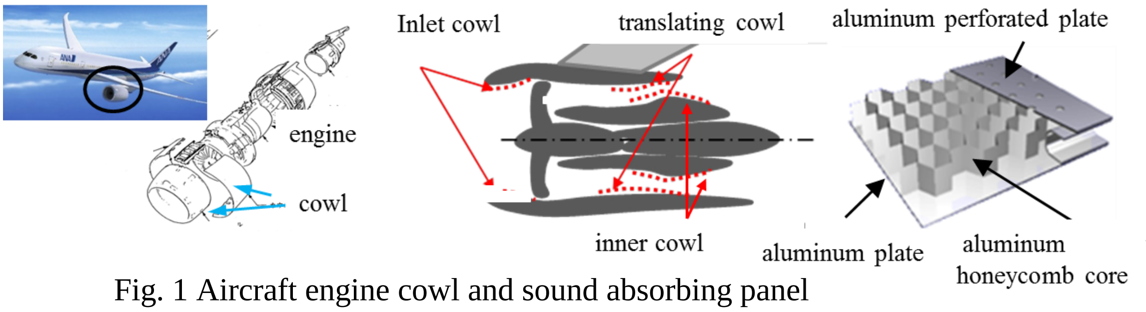


Fig. 1 Aircraft engine cowl and sound absorbing panel

Experimental method

Prototype of sound absorbing panel

The CFRP plate used for the sound absorbing panel was perforated using a direct pressure sandblasting apparatus (ELP-1TR, Elfotec Co., Ltd.) capable of metered discharge by control of the media blasting rate. The nozzle and workpiece were fed at constant speeds. The CFRP plate was first provided with a pre-perforated film of mask material (Fig. 2). Holes were formed in this mask using a photo etching technique from a negative printed on a transparent film with three different patterns (Fig. 3) of small holes with various diameters (1.0, 1.5, and 2.0 mm). Then, the plate and mask were mounted to a fixture and placed on a conveyor inside the blasting apparatus. The nozzle reciprocated right and left, and the entire plate was scanned by abrasive blasts. Blasting conditions, abrasive media, mask material, and processing conditions are given in Table 1. Using this method, when the hole diameter was 2 mm, for example, the target machining dimensions of the exit/entrance diameters of the hole were within 2.0 ±0.2 mm (Fig. 4). Next, a perforated CFRP plate, a non-perforated CFRP plate, a honeycomb core, and an adhesive film were prepared and assembled as a prototype sound absorbing panel with a honeycomb sandwich structure. During assembly, the adhesive film attached to the perforated plate was pierced with a needle or a small-diameter drill at each hole position. The materials used are listed in Table 2. The perforated CFRP plate, adhesive film, honeycomb core, adhesive film, and non-perforated CFRP plate were stacked and bonded using an autoclave ,and figure 5 is a photograph of the prototype sound absorbing panel after assembly. (Fig. 5). Lamination was performed at a pressure of 0.2 MPa using the autoclave's vacuum bag, and curing was done at 130°C for 2 h.

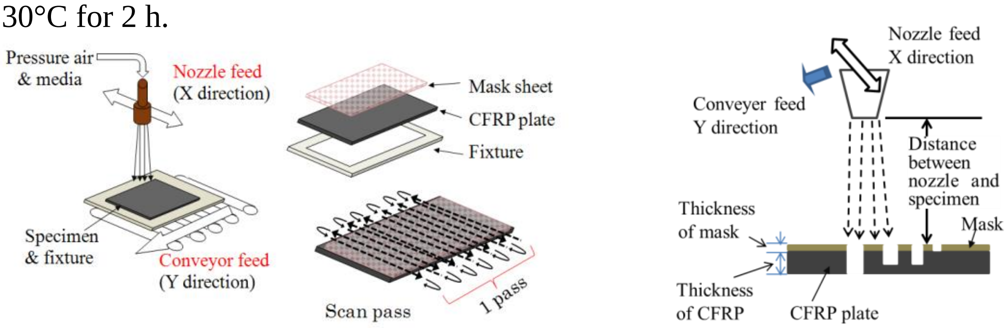


Fig. 2 Relationship of movement of blasting nozzle and CFRP plate with mask

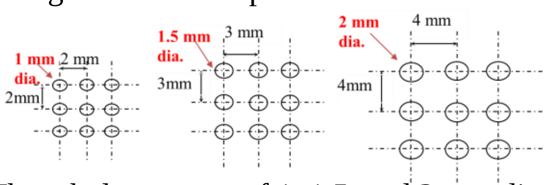


Fig. 3 Three hole patterns of 1, 1.5, and 2 mm dia.


Fig. 4 Blasting-perforated CFRP plate

Table 1 Blasting conditions

Item	Details
Mask material	Dry film resist: acrylic polymer resin film, 0.1 mm thick, 2 sheets
Abrasive media	White alundum #320, particle size 40 µm
Air pressure	0.15 MPa at the nozzle
Feed	X-axis: nozzle lateral speed, 8 m/min; Y-axis: conveyor speed, 20 mm/min
Nozzle	Diameter: 5 mm; distance between nozzle and work material: 120 mm

Table 2 Specimen materials adhesively assembled

Materials	Specifications and manufacturers
CFRP plates	Approximately 1.25 mm thick (3K woven fabric pre-preg made by Toho Tenax), and about 1.3 mm thick (pre-preg of Toho Tenax: 4 sheets of QFU1357U61A) laminated and cured
Honeycomb panels	Nomex honeycomb core (3B1901175CG-SAH 1/4-1.5, 10, and 20 mm thickness, opening size of about 6 mm, made by Showa Aircraft Co., Ltd.)
Adhesive film (epoxy type)	AXIOM (AX2114-N-0.060); applied to both sides of the impedance tube test piece and CFRP plate side for reverberation chamber test
Epoxy adhesive	Epoxy type: two-part liquid made by Struers: Epo-Fix; used on the porous plate side for the reverberation chamber test

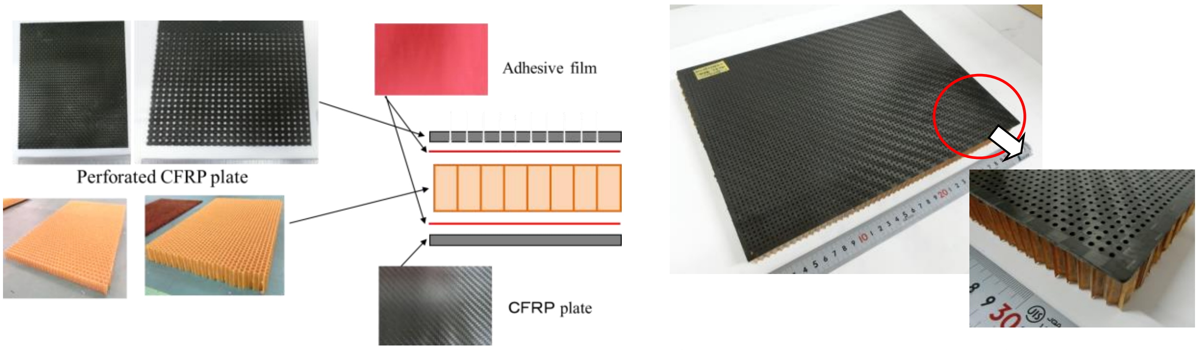


Fig. 5 Components and structures of sandwich panel for adhesive assembly (left), and photos of the prototype sound absorbing panel after assembly (right)

Cutting of sound absorbing test piece and measurement of sound absorption coefficient

To measure and evaluate the sound absorbing performance of the panel and determine its frequency, we used an impedance tube to measure the attenuation factor from the difference between the incident and reflected sound. Initially, the impedance test was carried out with a small cylindrical test piece 29 mm in diameter that was cut out from the prototype panel by numerically controlled machining (Fig. 6). The specimen was inserted into the impedance tube (Type 4206, Brüel & Kjær), wide-frequency (white) noise was generated at one end of the tube with a speaker, and the sound pressure was applied normal to the specimen (Fig. 7). The difference in time between the incident and reflected sound was analyzed by incidence sound absorption rate measurement software at a sampling period of 10 Hz to obtain the peak frequency and the normal incident sound absorption coefficient (methods ASTME1050-12 and ASTAME2611-09, respectively) [3].


Fig. 6 Disk specimen

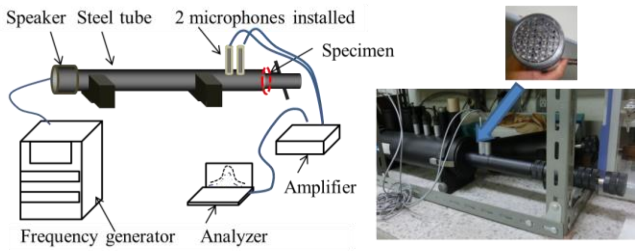


Fig. 7 Impedance tube testing setup

Large prototype of sound absorbing panel

To test our design in an anechoic room, where we can employ a damping method to measure the attenuation of room sound by reflection, we needed a larger panel. A B4 size (257 × 364 mm) CFRP perforated plate was prepared by blasting in the manner described above. For bonding with the honeycomb core material, we used epoxy liquid adhesive with adequate viscosity instead of adhesive film. The reason for using liquid adhesive was to reduce plugging of the holes by the adhesive film. Next, a sound absorbing panel of B3 size (364 × 515 mm) was produced by adhering two assembled B4 panels to a separately prepared B3 size CFRP plate with an adhesive film. Next, we gathered 6 sets of bonded assemblies, laid the edges of these panels side by side on a flat plate, and joined them with tape to form a 1-m^2 sound absorbing panel (Fig. 8).

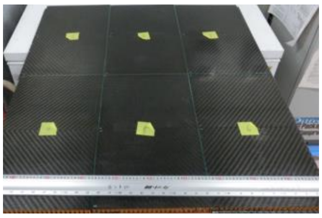


Fig. 8 Assembly of 1-m^2 sound absorbing panel

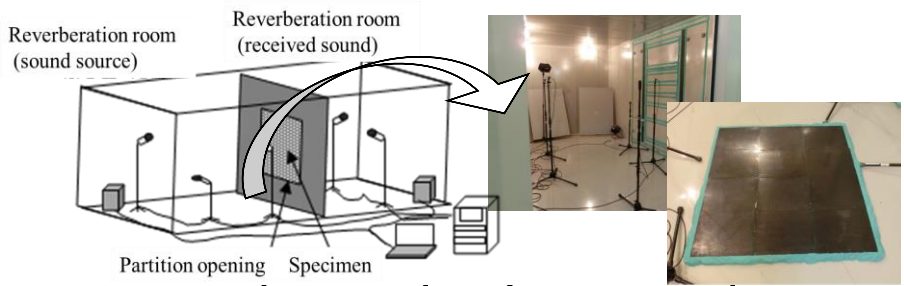


Fig. 9 Overview of equipment for evaluating acoustic characteristics, and a reverberation room and set up of a sound absorbing panel

Measurement of sound absorption coefficient of large sound absorbing panel

The sound absorption coefficient was measured using a reverberation chamber to evaluate the 1-m^2 sound absorbing panel. Measurement was carried using equipment (DS-2000 System, Ono Sokki Co., Ltd.). At this time, clay was applied to the edges of the sandwich panel to fill the gaps and prevent influence from the side surfaces (Fig. 9). Microphones were installed in the sound source and receiving rooms, and the DS-2000 system performs real-time 1/3 octave analysis. Initially, only the sound source room (24.82 m^3) was used. As described above, the perforated CFRP plate specimen was 1 m × 1 m × 21 mm thick and had holes 2 mm in diameter.

Test results

Figure 10(left) shows partial results for the measurement of specimens 1 and 2 (hole diameter of 2.0 mm. Using the prototype 1-m^2 sound absorbing panel, the sound absorption rate was measured in the reverberation chamber, and as a result, sound absorbing performance with a sound absorption peak frequency of 1,600 Hz and a maximum sound absorption rate of 0.61 was obtained (Fig. 10 right).

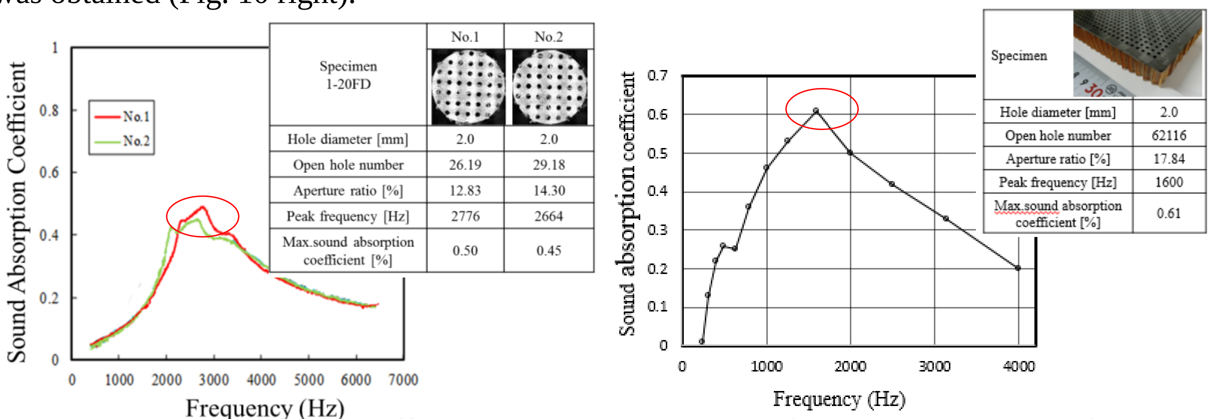


Fig. 10 Sound absorption coefficient measurement results of relationship between frequency and absorption coefficient, impedance tube result (left) and reverberation room result (right).

Consideration

A Helmholtz resonator has a structure in which a cavity is placed behind a plate with a narrow hole. The air in the hole acts as a mass and the air in the cavity functions as a spring to constitute a vibration system, and resonance occurs when a sound having the same frequency as the system's natural frequency is incident and generates heat by viscous friction in the hole. Thus, this structure attenuates sound by changing it to heat via friction (Fig. 11) [4].

The combination of the porous plate and the honeycomb structure is a resonant sound absorber that incorporates multiple Helmholtz resonators, and the sound absorption coefficient of the sound absorbing panel is determined by factors such as the size of the resonator and the viscous resistance value of the holes. Since it is difficult to accurately calculate the viscous resistance value of the holes, it is experimentally obtained by acoustic impedance measurement [5]. A calculation is made to predict the sound absorption coefficient of the sound absorbing panel, and the relation between the frequency and the normal incident sound absorption rate is analyzed by software. The acoustic impedance density Z_R at the resonance frequency of the resonator is expressed by the following formulas. Where *s* is the hole area, *h* is the perforated plate thickness, *ρ* is the air density, *R* is the viscous resistance of the hole, α is the hole radius, *r* is the cavity radius (approximating the honeycomb cavity as a cylinder), *L* is the height of the cavity, *p* is the aperture ratio in the perforated plate, *c* is the velocity of sound, *V* is the cavity volume, and *f* is the resonance frequency.

$$Z_R = \frac{1}{p}\frac{R}{s} \quad (1)$$

$$f = c/2\pi \cdot \left(\frac{s}{Vh}\right)^{1/2} \quad (2)$$

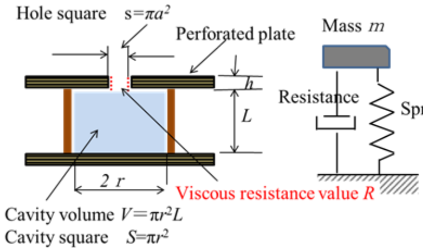


Fig. 11 Principle of Helmholtz acoustic resonance [4]

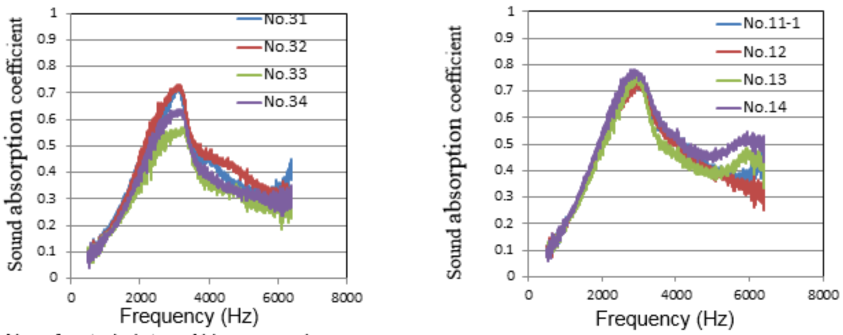
Equation (1) can be rewritten as $R = spZ_R$. We assume that the volume of the inlet hole is much smaller than the volume of the cavity; that is, *h*s << *V*. Thus, resonance occurs inside the cavity when the oscillation *f* in in Eq. (2) is applied to the opening of the hole.

Here, we apply the result of Fig. 10 (No. 1 test piece), as an example, to Eq. (2). Assuming that the aperture ratio is 12.83 in a disk having a diameter of 29 mm, by substitution, $s = \pi \times 1\ \mathrm{mm}^2 \times 12.83 = 12.83\ \mathrm{mm}^2\ \pi$, $V = \pi \times (29\ \mathrm{mm}/2)^2 \times 20\ \mathrm{mm} = 4{,}205\ \mathrm{mm}^3\ \pi$, $h = 1.25$ mm. The theoretical resonance frequency is derived as $1/2\pi \times 340\ \mathrm{m/s} \times (12.83\ \mathrm{mm}^2/4{,}205\ \mathrm{mm}^3\ \pi/1.25\ \mathrm{mm})^{1/2} = 2{,}673$ (Hz). Since the peak frequency of the measurement result was 2,776 Hz, which is close to this value, it is considered that measurement was successfully performed.

However, in the test of the 1-m^2 panel in the reverberation room, the average value of the aperture ratio of the divided plates was 17.84%. When this value is applied to the mathematical expression as described above, by substituting $s = (1{,}000\ \mathrm{mm})^2 \times 0.1784 = 17{,}8400\ \mathrm{mm}^2$, $V = (1{,}000\ \mathrm{mm})^2 \times 20\ \mathrm{mm} = 2\times 10^7\ \mathrm{mm}^3$, and $h = 1.25$ mm, we obtain theoretical values; $f = (1/2\pi) \times 340\ \mathrm{m/s} \times (178{,}400\ \mathrm{mm}^2/(2\times 10^7\ \mathrm{mm}^3)/1.3\ \mathrm{mm})^{1/2} = 4{,}482$(Hz). However, in the actual measurement result, the peak frequency was around 1,600 Hz, an obviously large difference.

The following points are credible causes: (1) The distribution of peak frequencies varied due to variations of 12% to 22% between the aperture ratios of the small disk panel and the 1-m^2 panel. (2) In the reverberation room, the sound absorbing performance was evaluated by using a 1-m^2 test piece for the sake of convenience, due to current limitations of the test piece fabrication process, whereas the test is usually performed with a 2-m^2 specimen. (3) In the reverberation room, the influence of scattering was more than expected because sound comes from many directions. In the test results using the impedance tube with perforated plates having hole diameters of 1.0 mm and 1.5 mm, data with a sound absorption coefficient of 0.8 or more were also obtained. Therefore, even in the case of 2 mm, it is considered that a higher sound absorption coefficient can be obtained by adjusting the honeycomb core thickness and the opening ratio and searching the resonance region. It should be noted that, due to space limitations, we omitted the results of a hole size of 1.0 mm and 1.5 mm.

From the past research, similarly shaped aluminum sound absorbing panels and CFRP panels were prototyped and the results of impedance tube test are shown in figure 12. In this test result, it is found that the sound absorption coefficient is slightly higher than that of CFRP made of aluminum rather than it. It was determined whether this difference is due to a difference in material or due to a slight difference in the shape of the hole due to the difference in processing method between drilling with aluminum hole and blasting holes with CFRP. It is necessary to further pursue in the future.



Al perforated plate + Al honeycomb 1.95mm dia. cylindrical shaped holes by drilling, max absorption coefficient 0.72

CFRP perforated plate+ Nomex honeycomb 1.9mm dia. slight taper shaped holes by blasting, max absorption coefficient 0.76

Fig. 12 Result of sound absorption rate evaluation test of aluminum panels and CFRP panels

Summary: This research can be summarized as follows:

1) Perforations were fabricated in CFRP plates by blasting and the plates were bonded to a honeycomb core to produce a sound absorbing panel.

2) Measurement of the sound absorption coefficient and peak frequency were carried out with a small cylindrical specimen for direct incidence sound absorption measurement and a normal incidence sound absorption coefficient (impedance tube) measurement device. Measured values nearly matched the theoretical values.

3) A sound absorbing panel of 1 m^2 was prepared and its sound absorption coefficient was measured in a reverberation room. Although a sound absorbing effect was obtained, the peak frequency was lower than the theoretical value.

From the above, we clarified that a CFRP perforated plate made by blasting can absorb sound and that the manufacturing process is effective.

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